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EMISSION AND LEACHING POTENTIAL OF MERCURY FROM FLUE GAS DESULFURIZATION (FGD) MATERIAL AMENDED SOIL

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WESTERN KENTUCKY UNIVERSITY

Report for Sponsored Research

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EXECUTIVE SUMMARY

The release of mercury (Hg) into the atmosphere, infiltration and uptake by plants from flue gas desulfurization (FGD) material-amended soils was studied. The project was carried out in three phases: (1) laboratory study, (2) field study, and (3) life cycle analysis (LCA). In the laboratory study, factors controlling the release of Hg from FGD by-product amended soil were investigated under a well-controlled greenhouse environment. The field study was carried out based on results obtained from laboratory greenhouse studies. Life cycle analysis was carried out to calculate the release of Hg from the FGD material-treated soils under a specific model to evaluate the environmental impacts associated with the addition of the three FGD materials used in this study.

Three FGD materials obtained from two coal combustion power plants were used. The SNO FGD material was obtained from the S-plant, which used a wet limestone, natural oxidation FGD process for sulfur dioxide (SO_2) emission control. Two FGD materials, (i.e., AFO Gypsum and AFO-CPS) were collected from the A plant, whose FGD process was operated under forced oxidation mode.

Results obtained from this study are summarized as follows:

Emission of Hg

Based on greenhouse studies, the Hg concentration in the soil, types of FGD material, and possibly the moisture content of the soil were found to affect the emission of Hg from FGD material amended soil. Results from greenhouse studies showed that, for a given FGD material, the total mass of Hg emissions increased as the amount of Hg in the soil increased. However, soils treated with different FGD materials showed different Hg emission behaviors. The SNO treatment had the highest Hg emission flux when compared to the other two FGD materials with the same amount of dosage. Due to concentration levels of Hg in the AFO-Gypsum and AFO-CPS FGD materials, the soils of the two AFO treatments contained a higher Hg concentration than the SNO treatment. It was found that, with 1% SNO FGD material treatment, the emission of Hg increased about 340% when the moisture of the soil increased from 17 to about 28.5%. The moisture of the soil was calculated from the mass balance of irrigation water and infiltration.

The ratio of total Hg in the soil released into the atmosphere was also calculated. Based on results from greenhouse studies, during the testing period, less than 1% of Hg was emitted into the atmosphere when the SNO FGD material was used with chicken litter as a soil amendment. In the case of AFO-Gypsum and AFO-CPS, the mass of the Hg emission was less than 0.8% and 0.02%, respectively, of total Hg in the soil.

Field studies showed that nearly 6% of the total Hg that was added to the soil as a result of SNO treatment was released into the gaseous phase. The ratio was found to be much higher than what was observed in the greenhouse studies. It was likely due to an increase in contact between the carrier air and soil-FGD material mixture in the field study. In the greenhouse study, unlike the field study, less carrier air was in contact with the deeper layer of the soil-FGD material matrix. The sampling chamber used in the field

study was inserted approximately 2cm into the soil to make sure no ambient air slipped into the chamber from the contacting point between the edge of the chamber and soil. As a result, it was likely that some air was pulled through the soil matrix and had carried more Hg from the matrix. However, the effect did not apply to the other two FGD materials, About 0.3 and 0.01% of the total Hg was released into the atmosphere for the 1% AFO-CPS and AFO-Gypsum treatments.

The observation implied that the emission of Hg from the SNO FGD material may be mass-transport controlled. In the case of the other two materials, the chemical process might be more important. However, the mechanisms that controlled the release of Hg from the FGD material needs further investigation.

Uptake of Hg by Plants

The concentration of Hg in the soil and types of FGD materials are likely the most important factors that controlled the uptake of Hg by plants during testing. With the same amount of FGD material, the Batch Three of the greenhouse study showed that the highest Hg concentration in the plant was observed in the SNO FGD material treatment. Although the addition of AFO-Gypsum and AFO-CPS produced higher Hg concentrations in the soil, the uptake of Hg by plants was not as quick as what was observed in the SNO treatment.

From greenhouse studies, less than 0.01% of the total Hg in the soil was taken up by the plants in the SNO treatment. For AFO-CPS and AFO-Gypsum FGD materials, the uptake of Hg by the plants was less than 0.0002 and 0.005%, respectively.

Higher ratios of Hg were taken up by grass when compared to the corn used in the greenhouse studies. It was found that about 0.5% of the total Hg in the soil as a result of the addition of SNO was taken up by the grass. In the case of AFO-CPS and AFO-Gypsum, the uptake ratio was about 0.09 and 0.2%, respectively, of the total Hg. Although the experimental conditions were quite different between the field and greenhouse, results implied that different plants might have different abilities to uptake Hg from soil.

Release of Hg into Infiltration

No detectable Hg concentration level was found in all infiltration samples collected from the three batches of greenhouse studies. All the Hg concentration levels were less than 0.1 ppb of detection limits. By taking the amount of infiltration collected during each experiment, less than 50 ng of Hg was released into the infiltration.

The lysimeter system applied in the field study did not collect infiltration effectively. Only infiltration samples from A (blank) and one of the C (1% AFO-CPS) batches were available. As with the laboratory study, no detectable Hg level was observed in these samples.

Effect of FGD Material Additions on the Yield of Plants

According to the results from Batch Two of the greenhouse study, the addition of SNO FGD material showed a negative effect on the growth of corn. This conclusion was validated by the results from both Batch Three and field studies.

In the case of AFO-Gypsum, the total mass of corn did not show observable increases with 1% of AFO-Gypsum treatment in both Batch Three and field studies. But with 10% treatment, the total mass of the plants was significantly higher than the blank soil. Although not many data points demonstrated the trend, the addition of AFO-gypsum probably had a positive effect on the growth of the plants.

As with the SNO FGD material, the AFO-CPS material showed negative effects on the growth of both corn and grass. It is likely due to a higher uptake of Hg and other trace elements from the AFO-CPS treated soil.

Release of Hg from FGD Material-Amended Soil

The life-cycle release of Hg using FGD material as a soil amendment was calculated based on the boiler operation conditions of the two plants where the FGD materials were obtained. Also, it was assumed that 100% of the FGD materials produced from the processes were used as soil amendments. Results of the calculation can be seen in Table 4.5. As shown in the table, the SNO FGD material released the most Hg during the testing period. The AFO-Gypsum treatment had the least release of Hg.

However, one should note that the results used for the calculation were based on the data collected during an 8-week field study. Release of Hg from FGD material amended soil is expected to have impacts in human toxicity and ecotoxicity. However, due to the limited project period, it is unknown how long the release of Hg will last or if the magnitude will change over time.

Treatment	FGD Material to Soil Ratio[1]	Soil Hg[2] 0-15[3]	Emission	Hg uptake	**Total**
	% (wt/wt)	**ng/g**	**kg of Hg/1000kg of Coal Burned**		
B-Field	SNO 1.0	39±8	2.26E-06	1.95E-07	2.46E-06
C-Field	AFO-CPS 1.0	4790±30	1.33E-07	1.08E-06	1.22E-06
D-Field	AFO-Gypsum 1.0	71±18	2.79E-07	1.58E-07	4.37E-07

1. INTRODUCTION

Kentucky is ranked second in the nation in installed flue gas desulfurization (FGD) scrubber capacity for coal-fired power plants. As a result, large amounts of FGD by-products are produced every year. An increase in the utilization of FGD by-products (e.g., agricultural land application) creates significant economic opportunities for the state. However, concerns about the release of hazardous elements have inhibited the usage. The goal of this project was to evaluate the environmental impact associated with the land application of the FGD by-product. In this project, the emission, leaching, and bioaccumulation of Mercury (Hg) from soils, which were amended using FGD by-products, was quantitatively and mechanically determined.

The objectives of this study were:

1. To measure the emissions of Hg from FGD by-product amended soil as well as the release of Hg and other trace elements into infiltration;
2. To investigate the uptake of Hg and other trace elements by plants;
3. To correlate the emission/release of Hg and other trace elements to the types of amendments and land application conditions;
4. To elucidate the mechanisms controlling the emission and release of Hg;
5. To determine the Hg exchange between air and amended soil; and
6. To conduct Life Cycle Analysis (LCA) for environmental sustainability evaluations.

2. Experimental

2.1. Experimental Approaches

The study was carried out in three phases (i.e., laboratory study, field study, and life cycle analysis)

2.1.1. Phase One: Laboratory Greenhouse Study

To elucidate the factors that control the emission of Hg from FGD by-product amended soils, a laboratory-scale study to monitor the emission under a well-controlled environment was first carried out. A set of greenhouse chambers whose dimensions were: width, length, and height of 30.48 cm, 30.48 cm, and 76 cm, respectively, were used. A schematic of a greenhouse chamber can be seen in Figure 2.1.

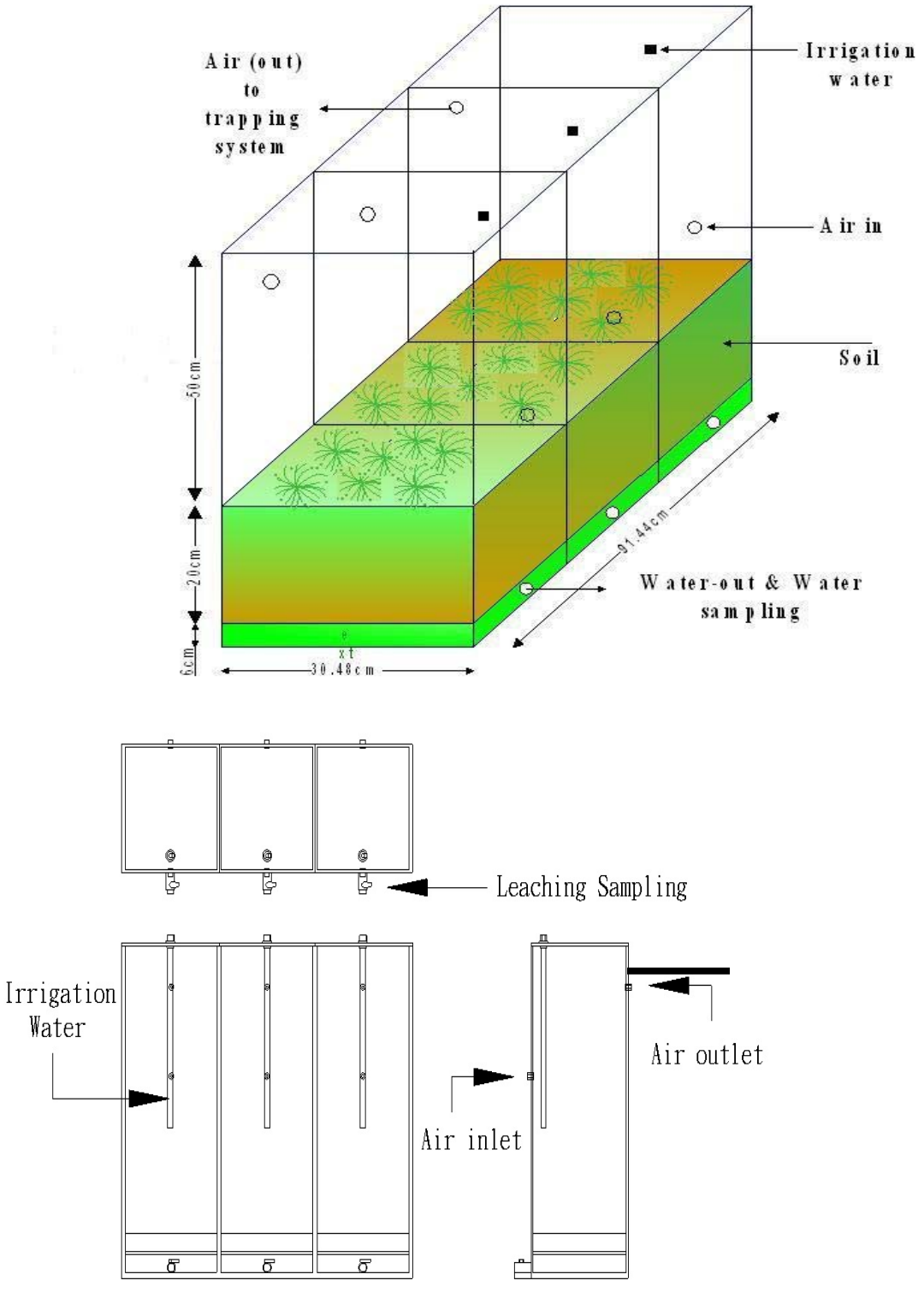


Figure 2.1 Schematic description of greenhouse chamber

As can be seen in the figure, each greenhouse chamber had an airflow inlet and outlet, an irrigation system, and an infiltration collection section. A layer of reticular polyvinyl chloride material was placed at the bottom of the soil section to separate soil from infiltrate. The depth of the soil in the greenhouse chamber was about 15cm, which is similar to the depth of the top soil in on typical farm land. Therefore, the infiltration collected from the greenhouse chamber had similar contact time with soil compared with that on farm land.

Merucry emissions were measured using a purge and trap sampling approach, which incorporated an air sampling pump and halogenated carbon traps that were employed to capture multiple mercury species (total Hg) in air. A halogenated carbon trap consisted of a 10mm o.d. glass tube that was filled with granules of halogenated carbon over about 12cm in length. Three 1-cm segments of glass wool were filled at the tip, middle, and end of the sorbent trap, which divided the halogenated carbon into two sections. For a given chamber, one carbon trap was placed at the inlet port, located at the center (43cm from the bottom and 15.2 cm away from the two edges) of the front side of the greenhouse chamber. Another sorbent trap was place at the outlet port, which is 15.2cm away from each side of the edge and 65cm above the bottom of greenhouse chamber. While the experiment was carried out, the air sampling pumps pulled air through the head space above the soil. Airflow through each chamber was controlled at 2.4L/minutes. The carbon trap placed at the inlet port of the chamber removed mercury from the ambient air that entered the chamber. The "mercury-free" air passed over exposed surfaces of soil to provide oxygen for the plants and to transport gaseous mercury released from the soil into the carbon trap installed at the outlet port of the chamber. A water trap was set up at the outlet port of the chamber to remove moisture from the outflow air. The setup of the sampling system can be seen in Figure 2.2.

The irrigation system installed at the top of each section of the greenhouse chamber supplied water for plant growth. The irrigation water volume was determined by the corn growth. The amount of water added into each chamber was recorded. A total of 2850, 500, and 1690 liters of water were added into the chambers during the periods of Batch One, Two, and Three studies, respectively. The operation of a simulated sunlight system was controlled. The sunlight system was turned on for 5 hours every day when the corn plants were seedling and 8 hours when the corn started to grow. The temperature and exposure to sunlight were controlled constantly for each batch. The pictures of the greenhouse studies can be seen in Figure 2.3.

The soil used in the laboratory study was collected from the Western Kentucky University farm located in Bowling Green, Kentucky. The top soil (a depth of 15 cm from the surface) was collected, air-dried and analyzed for pH, Hg, and other trace elements. Flue gas desulfurization (FGD) material used in this study was collected from two coal combustion power generation facilities, which were referred to as S and A plants in later discussions. The S plant, located in southern Illinois, used a wet limestone, natural oxidation FGD process for SO_2 emission control. The FGD material collected from this plant is labeled as SNO in the following discussion. Two FGD materials, (i.e., AFO Gypsum and AFO-CPS) were collected from the A plant, which is located in the

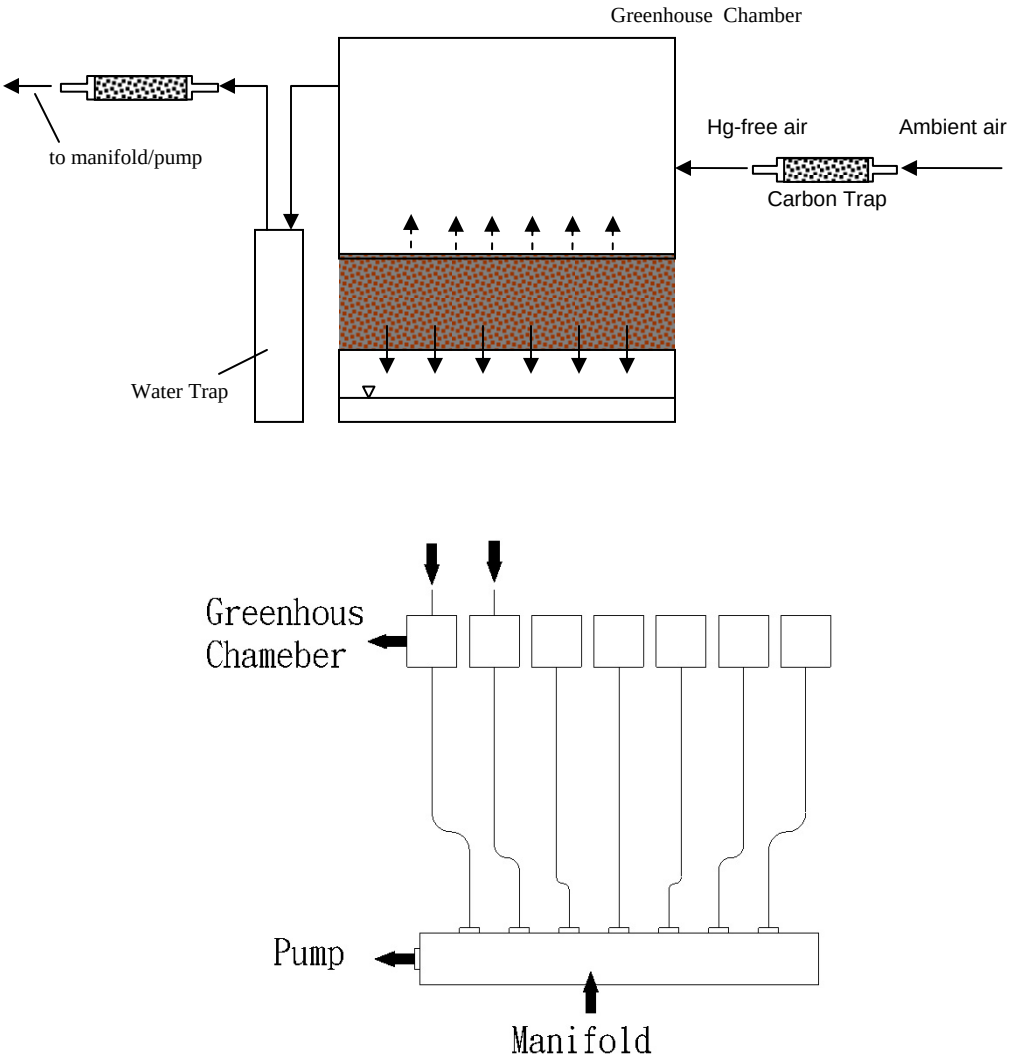


Figure 2.2 Schematic description of Hg emission sampling system

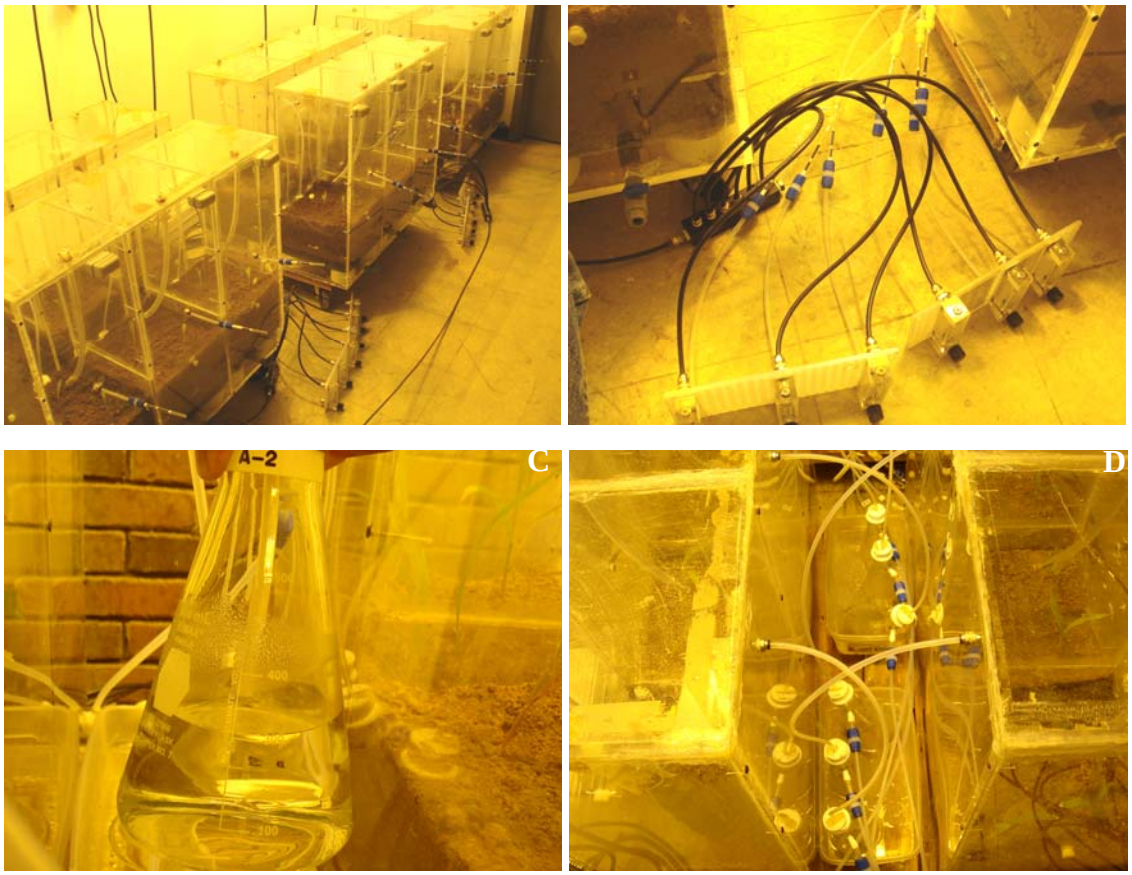


Figure 2.3 Laboratory greenhouse study

northwest portion of West Virginia. The FGD process of the unit was operated under forced oxidation mode. The AFO-Gypsum was the FGD gypsum produced from the forced- oxidation process. The AFO-CPS was the sludge solid waste produced from the chloride purge stream wastewater treatment plant of the FGD process.

The laboratory greenhouse study was carried out in three batches. For a given batch, six different FGD by-product treatments (including blank) were tested. Each treatment was carried out in one chamber with three compartments. The formulations for each treatment in the three batches are summarized in Table 2.1. The moisture and mercury content in the material used in this study are listed in Table 2.2. The procedure and instrumentation used for the analysis are described in the following section.

The testing schedule for each batch of testing is listed in Table 2.3. As shown, each batch was carried out for 4 weeks.

Sweet Sundance (Hybrid) corn was grown in the greenhouse study.

Table 2.1 Formulation of FGD Material-amended Soils Tested in Greenhouse Study

	Batch One					
	Treatment 1-A	Treatment 1-B	Treatment 1-C	Treatment 1-D	Treatment 1-E	Treatment 1-F
Soil	15	15	15	15	15	15
SNO	0	0.03	0.15	0.3	1.5	3
SNO-Soil Ratio	Blank	0.2%	1%	2%	10%	20%
	Batch Two					
	Treatment 2-A	Treatment 2-B	Treatment 2-C	Treatment 2-D	Treatment 2-E	Treatment 2-F
Soil	15	15	15	15	15	15
SNO	0	0.15	0.38	0.75	1.13	1.5
Chicken litter	0.03	0.03	0.03	0.03	0.03	0.03
SNO-Soil Ratio	Blank	1%	0.26%	0.5%	7.8%	10%
	Batch Three					
	Treatment 3-A	Treatment 3-B	Treatment 3-C	Treatment 3-D	Treatment 3-E	Treatment 3-F
Soil	15	15	15	15	15	15
Chicken litter	0.03	0.03	0.03	0.03	0.03	0.03
SNO	0	0.15	0	0	0	0
AFO-Gypsum	0	0	0.15	1.5	0	0
AFO-CPS	0	0	0	0	0.15	1.5
FGD Material-Soil Ratio	Blank	1%	1%	10%	1%	10%

Unit: kg; The ratio between FGD material and soil is calculated from as received basis

Table 2.2 Moisture and Mercury Content of Soil, Chicken Litter, and FGD Material

Samples	Moisture, %	Hg
		ng/g
Soil	16.73	17±3
SNO	50.87	242
AFO-Gypsum	12.43	736
AFO-CDS	8.98	63315

Table 2.3 The Greenhouse Testing Schedule

Batch	Testing Date/time
One	04-04-2008~05-01-2008
Two	06-09-2008~07-06-2008
Three	08-19-2008~09-16-2008

2.1.2. Phase Two: Field Study

The field study was carried out at Western Kentucky University's farm, located in Bowling Green, Kentucky. A field area with a dimension of 7m×9m was used (Figure 2.4). The experiment field was divided into twelve 1m×1m plots with a ploughing depth of about 15cm. The soil was turned over by a tractor with a plough. There was a 1m space interval between each plot. Photos showing the preparation of the field can be seen in Figure 2.4.

Mercury emission from the soil in the field study was measured by a similar approach employed in the greenhouse study. A high-density polypropylene (HDPE) container with dimensions of 15 cm by 15 cm by 12 cm was used as the mercury sampling chamber. An airflow inlet port and outlet port were installed on two opposite sides of the container. The inlet and outlet ports were positioned 6 cm and 10.5 cm above the soil surface, respectively. A halogenated carbon trap was used for mercury measurement. The water trap was set up at the airflow outlet of the chamber before air was drawn through the carbon trap. Teflon tubings and Teflon fittings were used to establish a path for airflow. Mercury sampling was carried out continuously during the experimental period. The position of the chamber on the surface of each plot was changed every other day throughout the field study to collect representative samples. A flow rate of 2.36 L/min was controlled at each sampling chamber. The set up for mercury emission measurements can be seen in Figure 2.4.

A lysimeter (Hanna HI83900-60) was inserted at the center of each plot to collect infiltration (Figure 2.5). The ceramic tip of the lysimeter was leveled at 15cm (the bottom of the FGD amended soil after insert).

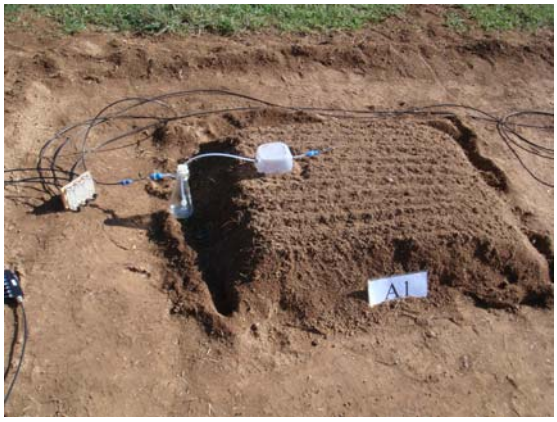
The testing schedule is shown in Table 2.4. Unlike the greenhouse study, fescue grass was used as the plant for the field study. The matrix of the testing can be seen in Table 2.5. Four FGD treatments (including blank) were studied. Each treatment was carried out in triplicate. For a given plot, 4.3kg of chicken litter and 8kg of designated FGD material (no FGD material in Treatment A) were added to the soil. The FGD material was mixed using a rolling plow until the mixture was visually homogeneous. The final setup is demonstrated in Figure 2.6.

The fescue grass from each plot was collected on 12/05/2008, six weeks after it was sowed. In each plot, the grass was collected from a 104 cm^2 area at the centers of the fou equally-divided square sections. A composite sample was made for each plot and dried for mercury analysis. The drying process can be seen in the following section.

(a) initial cultivation of soil

(b) applying FGD material

(c) mixing FGD material and soil



(d) Hg emission monitoring chamber setup

(e) lysimeter installation

(f) final setup after sowing seed

Figure 2.4 Field study preparation

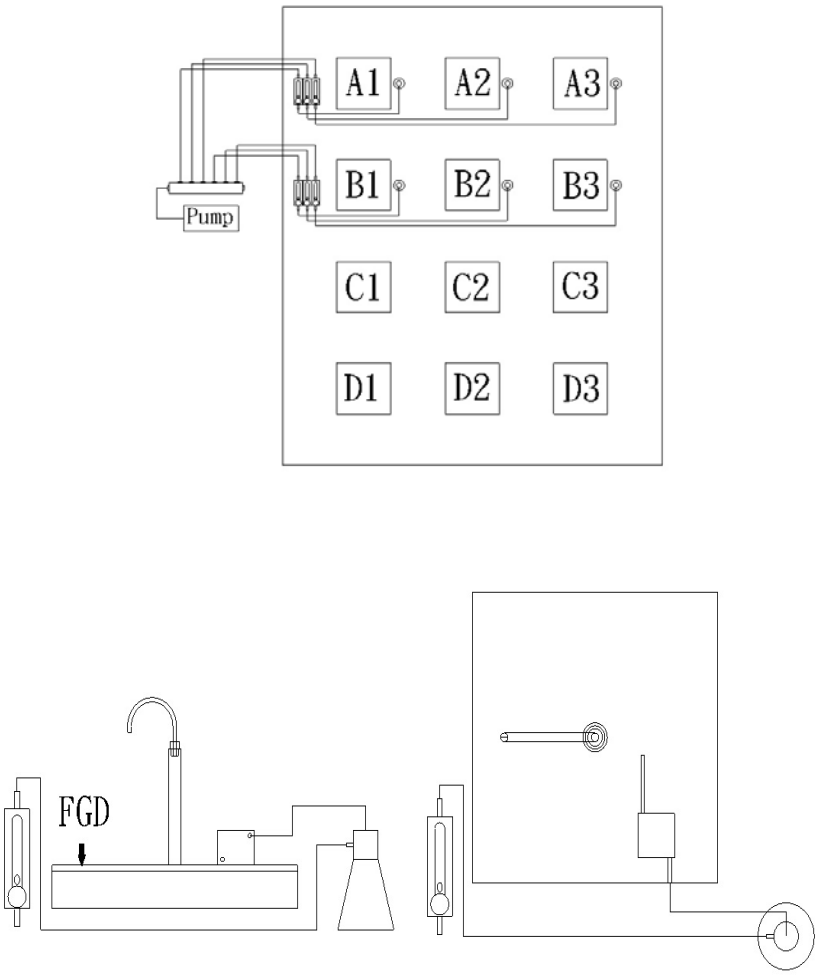


Figure 2.5 Sampling setup of field study

Four FGD material treatments were tested in the field study. A detailed matrix of each treatment can be seen in Table 2.5.

Table 2.4 Testing Matrix of Field Study

	Field Study			
	Treatment A-Field	Treatment B-Field	Treatment C-Field	Treatment D-Field
Chicken litter	4.9	4.9	4.9	4.9
SNO	0	8.1	0	0.0
AFO-Gypsum	0	0	8.1	0.0
AFO-CPS	0	0	0	8.1

unit:kg

Table 2.5 Testing Schedule of Field Study

Process	Date/time
Plow	10/10/2008
FGD mix soil	10/13/2008~10/14/2008
Trapping system set up and start	10/15/2008
Soil cultivate	10/15/2008~10/22/2008
Sowing	10/22/2008
First phase trapping	10/15/2008~11/14/2008
Second phase trapping	11/14/2008~12/05/2008

Figure 2.6 Progress of field study

Two cores of the soil sample with a diameter of 1.5cm were collected from the centers of each plot. The first core was from the top soil section with FGD material addition. The other core was collected from the 15-30cm section.

2.2. Sample Analysis

2.2.1. Soil Analysis

After each batch of the greenhouse study, four soil cores (0-15 cm depth) were collected from each of the 18 greenhouse chambers. Soil samples were air-dried, crushed, and screened through a 100-mesh (0.15-mm) sieve. Plant samples were also collected. The length of root, stem, leaf, and weight were measured for each plant. Plant

samples were then washed with de-ionized water before they were dried at 60 ^{o}C for 3 days. After drying, the plant samples were weighed and smashed into small pieces that passed 1-mm sieve. Both soil and plant samples were analyzed for Hg by a Hydra-C Automated Direct Hg Analyzer (Leeman Lab Prodigy-DV, Teledyne Leeman Labs, NH). Other chemical compositions were determined by either an Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES, Leeman Lab Prodigy-DV, Teledyne Leeman Labs, NH) or a cold-vapor atomic fluorescence spectroscopy analyzer (CVAFS, PS Analytical, UK) after digestion. A microwave digestion system (Milestone, Sholton, CT) was used for solid sample digestion by following USEPA Method 3015A.

Figure 2.7 Mercury Analysis Instruments (A)Solid: Hydra-C Direct Mercury Analyzer Operations Manual,(Leeman Lab Prodigy-DV, Teledyne Leeman Labs, NH). (B)Liquid: CVAA Automated Mercury Analysis System, (Leeman Lab Prodigy-DV, Teledyne Leeman Labs, NH).

2.2.2. Liquid Sample Analysis

The liquid samples, such as moisture of greenhouse chamber and infiltrate, were also analyzed for Hg and trace elements. Each of the liquid samples was separated into two sub-samples. For Hg analysis, one batch of samples was preserved by adding about 0.1g of potassium permanganate. The other batch of samples was adjusted to 5% of NH_3 for elemental analysis. Hg analysis was done by a CVAA Automated Mercury Analysis System, (Leeman Lab Prodigy-DV, Teledyne Leeman Labs, NH). For elemental analysis, microwaveassisted acid digestion using a Microwave Digestion System (Milestone, Sholton, CT) with USEPA Method 3015A were employed to prepare the samples for trace element analysis. An ICP-AES (Leeman Lab Prodigy-DV, Teledyne Leeman Labs, NH) and a CVAFS (PS Analytical, UK) were used for elemental analysis.

3. RESULTS

3.1. Laboratory Greenhouse Study

3.1.1. Effect of FGD Material Dosage

The effect of FGD by-product amendment dosages was investigated during the first batch of the greenhouse study. Results obtained from the batch one experiment are summarized in Table 3.1.

Table 3.1 Total Mass of Hg in Emission, Plants, Soil, and Infiltration under Different Dosages of SNO FGD Material

Treatment	FGD Material to Soil Ratio[1]	Total Hg[2]	Emission[3]	Plants			Soil[6]	Infiltration[7]
	% (wt/wt)	µg	µg	Yield, g[9]	ng/g[4]	ng[5]	µg/g	ng
A-1 (blank)	0	273	5.5±1.8	1.3±0.7	12.8±0.6	24±7	18.21±0.13	<48[8]
B-1	0.2	280	6.7±1.1	2.0±0.3	12.9±0.7	26±3	18.7±0.5	<47
C-1	1.0	314	8±3	2.1±0.7	12.4±1.0	26±9	21±2	<48
D-1	2.0	347	6±5	2.0±1.2	15.4±1.1	42±3	22.7±1.9	<47
E-1	10.0	711	3±2	1.4±0.3	23.4±1.5	33±8	43.1±1.2	<47
F-1	20.0	1260	7.8±1.7	2.1±0.5	30±4	62±19	70±14	<47

[1] as received basis
[2] the total Hg was calculated by the sum of total Hg in soil and the amount of Hg added into the soil as a result of FGD material addition
[3] the total mass of emission was determined by the amount of Hg captured by the carbon trap at the airflow outlet of the chamber
[4] ng of Hg in 1g of plant
[5] the total mass of Hg uptake by the plants was determined by the concentration of Hg in the plants and the total mass of the plants collected from each chamber
[6] dry basis
[7] the total mass of Hg in infiltration was determined by the concentration of Hg in filtrate and the volume of infiltrate collected at the end of experiment
[8] the Hg concentration level in the filtrate was below the method detection limit (MDL) of 0.1ng/mL.
[9] yield is calculated from the total mass of the plant (dry basis) collected from each chamber

Emission of Mercury

Figure 3.1 demonstrates the total mass of Hg release from the soil from each of the six SNO FGD material treatments. The expected total Hg in soil based on mass calculation was also included in the figure for each of the treatments. As shown, the emission of mercury from the SNO FGD material-treated soil did not increase as the total Hg in the soil increased. The correlation between Hg emission and Hg in the soil can be seen in Figure 3.1. The emission of total Hg increased 1.2 and 2.5 µg as the total Hg in the soil increased 13µg in Treatment B-1 and 41µg in Treatment C-1, respectively. However, the increasing trend was not found in the other three treatments. For example, in Treatment F-1, the expected total Hg in the soil was 1260 µg, which is about five times higher than the total mass of Hg in the un-treated batch. However, the emission of Hg from Treatment F-1 is about 2.3µg (or ~40%) higher than what is observed in the blank, which is similar to what was observed in Treatment C-1. Therefore, no observable correlation was found.

The ratio of Hg emissions to the total Hg in soil of each treatment can be seen in Figure 3.2. As shown, less than 3% of the total Hg was released into the head space of the greenhouse chamber during this batch of the study.

Uptake of Mercury by Plants

The correlation between the uptake of Hg by the plants and total mass of Hg in the soil is shown in Figure 3.3. It was found that the total uptake of Hg by plants increased as the Hg concentration in the soil increased. A high correlation coefficient (0.988) was observed.

Figure 3.4 shows the correlation between the plant Hg concentration and the total mass of Hg in the soil. It was found that the Hg concentration of plants remained relatively constant at Treatments A-1, B-1, and C-1. It started increasing as the total mass of Hg in the soil was higher than 300μg. In general, the concentration of Hg in the plants increased as the total Hg in the soil increased.

By comparing the total mass of Hg by plants and the total mass of Hg in soil (Figure 3.4), it was found that the uptake of Hg by plants was not proportional to the less than 0.0001% of the Hg found in the plants.

Release of Mercury into Infiltration

The concentration of Hg in the infiltrates collected from the bottom of each chamber was below the analytical detection limit of 0.1ng/mL. As a result, no detectable Hg was released into the infiltration.

Yield of Plants

Figure 3.6 shows the yield of plant as a function of total mass of mercury in soil. Since the total experiment duration for each batch is short, the difference between each treatment is not significant. However, it was found that the addition of SNO FGD material showed some effects on plant growth. The addition of 0.1% SNO FGD material increased the growth by nearly 50%. However, the increase did not occur with a higher dosage of the same FGD material.

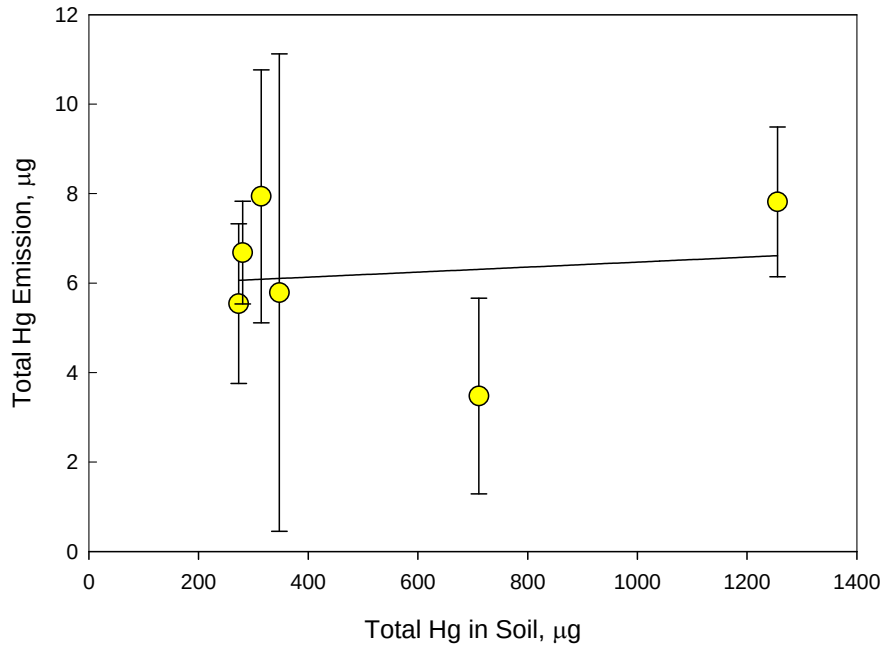


Figure 3.1 Correlation between emissions of Hg and total mass of Hg in soil treated with various dosages of SNO FGD material. (Batch One)

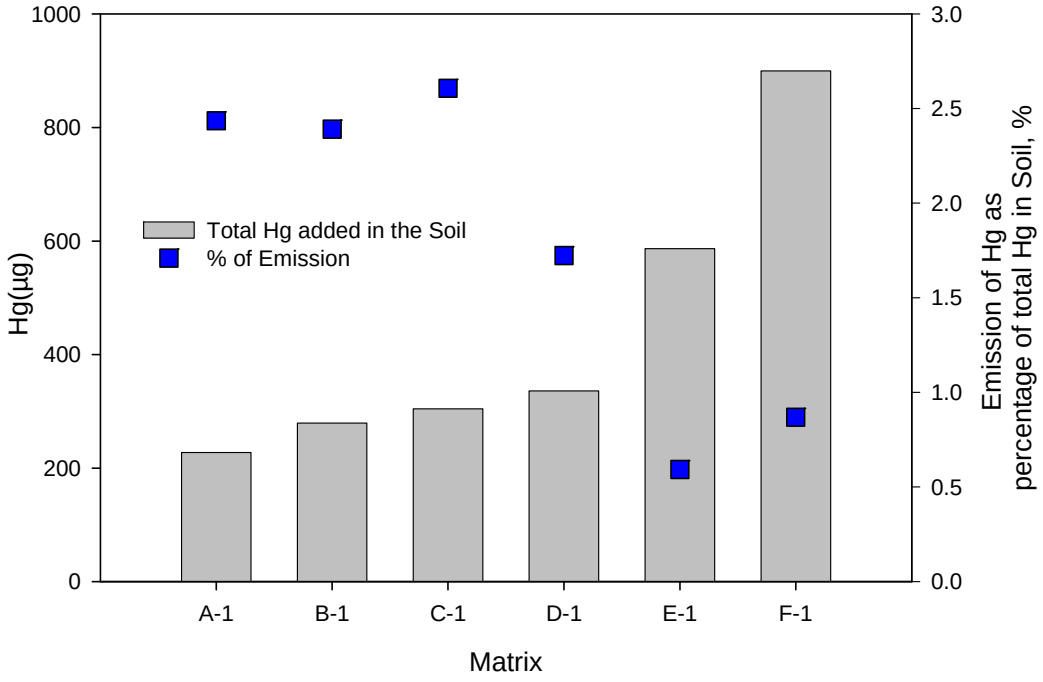


Figure 3.2 Ratio of Hg emissions to the total Hg in soil. (Batch One)

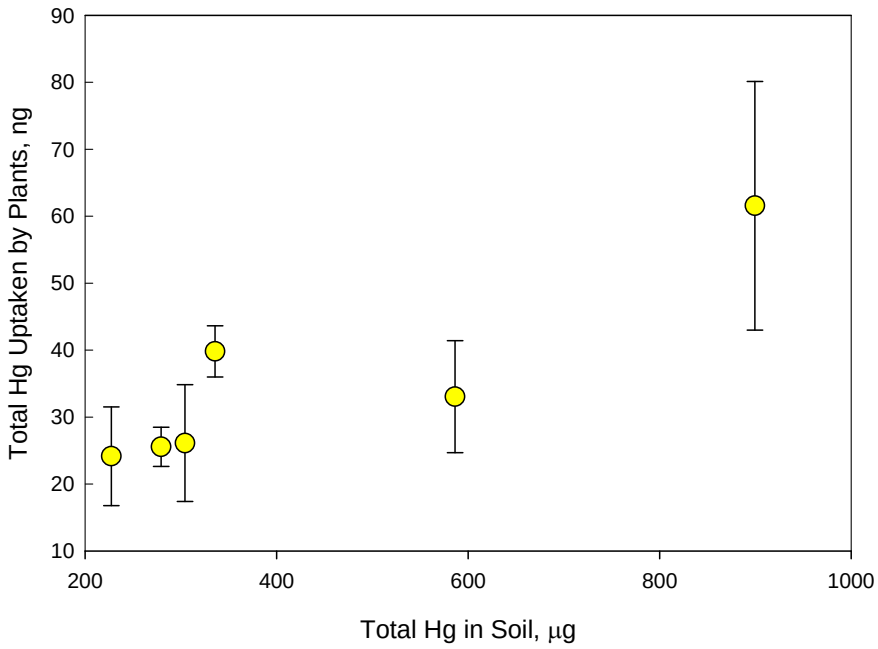


Figure 3.3 Correlation between total mass of Hg uptake by plants and total mass of Hg in soil treated with various dosages of SNO FGD material. (Batch One)

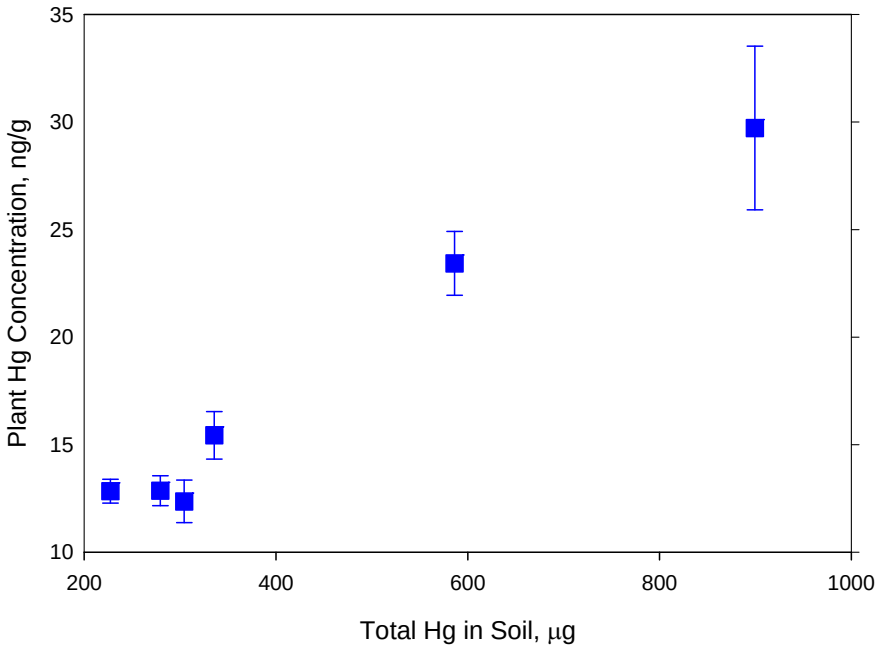


Figure 3.4 Correlation between plant Hg concentrations and total mass of Hg in soil treated with various dosages of SNO FGD material. (Batch One)

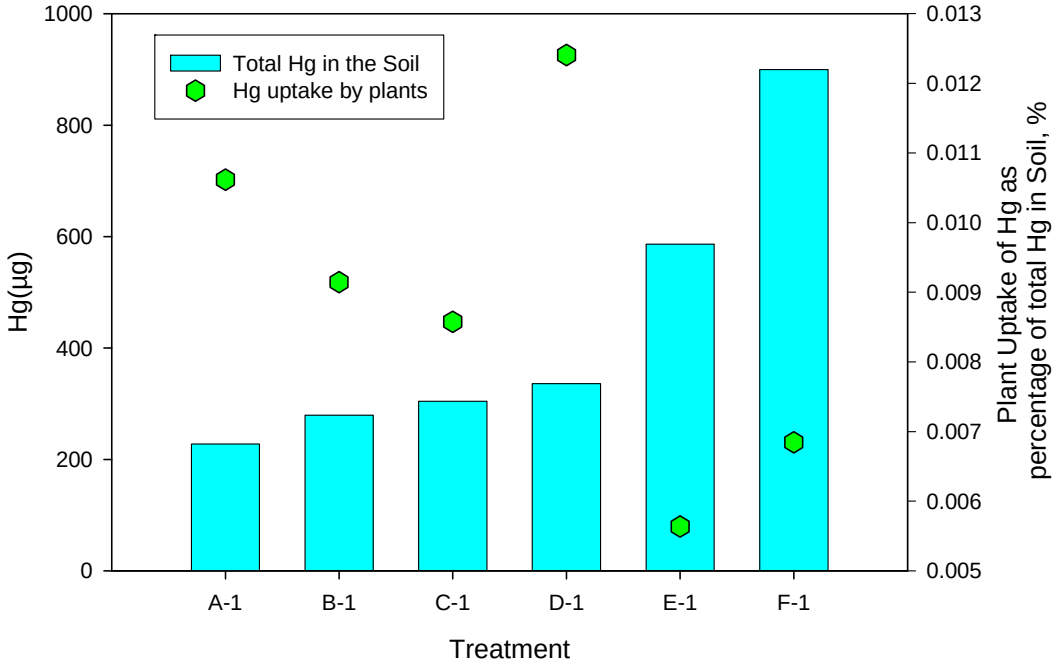


Figure 3.5 Ratio of Hg uptake by plants to the total Hg in soil (Batch One)

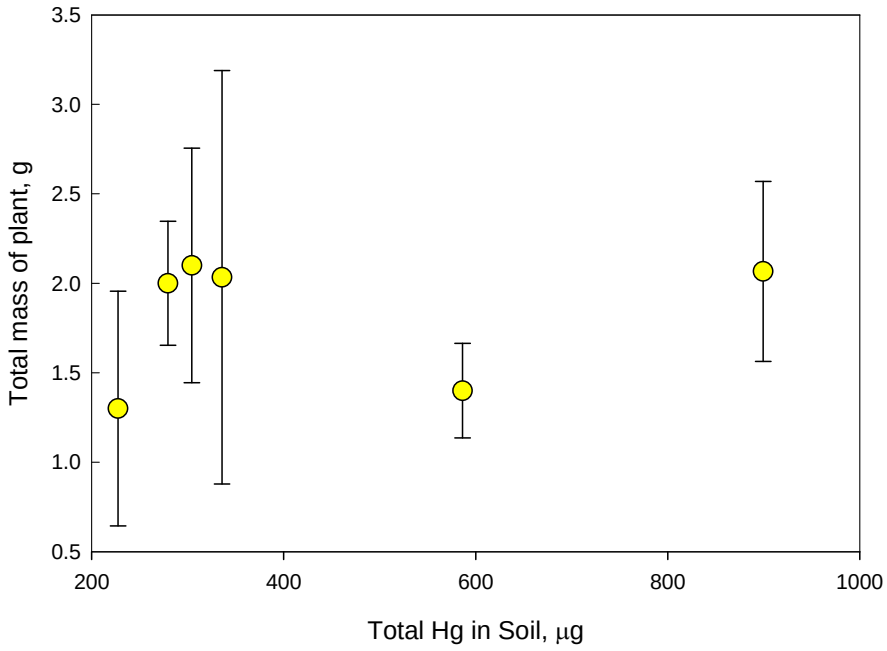


Figure 3.6 Plant yield from Batch One

3.1.2. Effect of SNO FGD Material with Chicken Litter

The effect of FGD by-product amendment dosages with the addition of chicken litter was studied during the second batch of the greenhouse study. Results obtained from the Batch Two experiment can be seen in Table 3.2.

Table 3.2 Total Mass of Hg in Emissions, Plants, Soil, and Infiltration under Different Dosages of SNO FGD Material with 1% Chicken Litter

Treatment	FGD Material to Soil Ratio[1]	Total Hg[2]	Emission Dry[3]	Plants			Soil[6]	Infiltration[7]
	% (wt/wt)	µg	µg	Yield, g[9]	ng/g[4]	ng[5]	µg/g	ng
A-2 (blank)	0	304	0.29±0.09	1.56±0.15	5.43±0.06	8.4±1.2	20.3±1.2	<4[8]
B-2	1.0	367	0.61±0.06	1.8±0.4	8.3±1.7	16±6	22.1±0.6	<5
C-2	2.5	465	1.07±0.03	1.23±0.15	14±3	17±3	44.7±0.3	<7
D-2	5.0	622	1.6±0.2	1.60±0.10	22±4	42±8	42±8	<8
E-2	7.5	783	1.4±0.2	0.9±0.2	26±6	20.4±1.3	44±2	<11
F-2	10	940	1.9±0.3	0.8±0.0	21±3	17±2	53±7	<17

[1] as received basis
[2] the total Hg was calculated by the sum of total Hg in soil and the amount of Hg added into the soil as a result of FGD material and chicken litter addition
[3] the total mass of emission was determined by the amount of Hg captured by the carbon trap at the airflow outlet of the chamber
[4] ng of Hg in 1g of plant
[5] the total mass of Hg uptake by the plants was determined by the concentration of Hg in the plants and the total mass of the plants collected from each chamber
[6] dry basis
[7] the total mass of Hg in infiltration was determined by the concentration of Hg in filtrate and the volume of infiltrate collected at the end of experiment
[8] the Hg concentration level in the filtrate was below the method detection limit (MDL) of 0.1ng/mL.
[9] yield is calculated from the total mass of the plant (dry basis) collected from each chamber

Emission of Mercury

Table 3.2 demonstrates the total mass of Hg release from the soil from each of the six SNO FGD material treatments with the addition of 1% chicken litter. The expected total Hg in soil based on mass calculation is also included in the table for each of the treatments. As shown, the emission of total mercury from the SNO FGD material/chicken litter-treated soil increased as the total Hg in the soil increased. The correlation between Hg emission and Hg in the soil can be seen in Figure 3.7. As shown in the figure, the increase of Hg in the soil increased the total mass of Hg emitted into the head space of the greenhouse chamber during the sampling period.

The ratio of Hg emissions to the total Hg in the soil of each treatment can be seen in Figure 3.8. As shown, less than 0.45% of the total Hg was released into the headspace of the greenhouse chamber during this batch of the study.

Uptake of Mercury by Plants

The correlation between the uptake of Hg by the plants and total mass of Hg in the soil is shown in Figure 3.9. It was found that the total uptake of Hg by plants increased as the total mass of Hg in the soil increased to a concentration level of 622ng. The uptake of Hg decreased to about 20ng as the total Hg mass in soil increased.

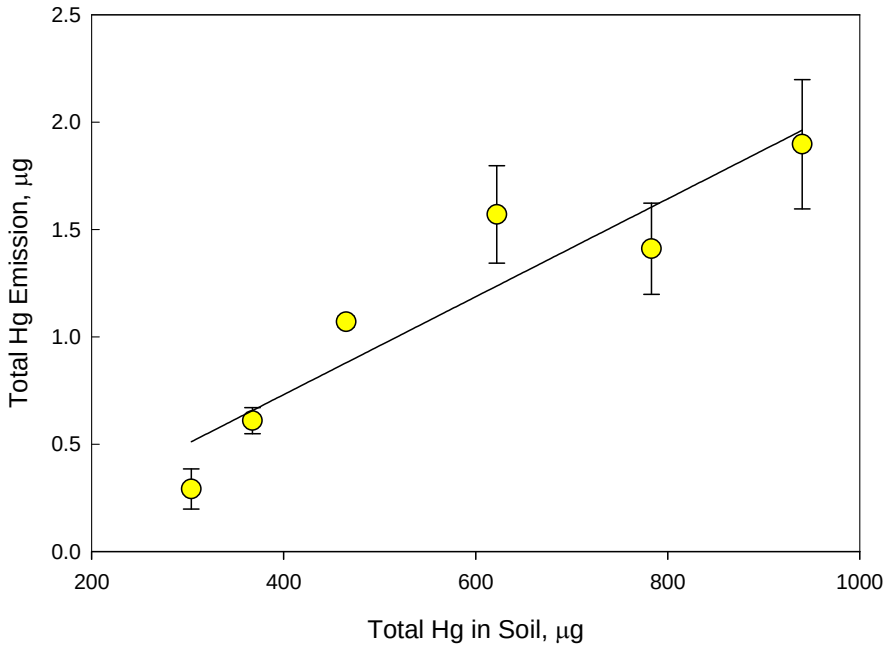


Figure 3.7 Correlation between emission of Hg and total mass of Hg in soil treated with various dosages of SNO FGD material and 1% of chicken litter.

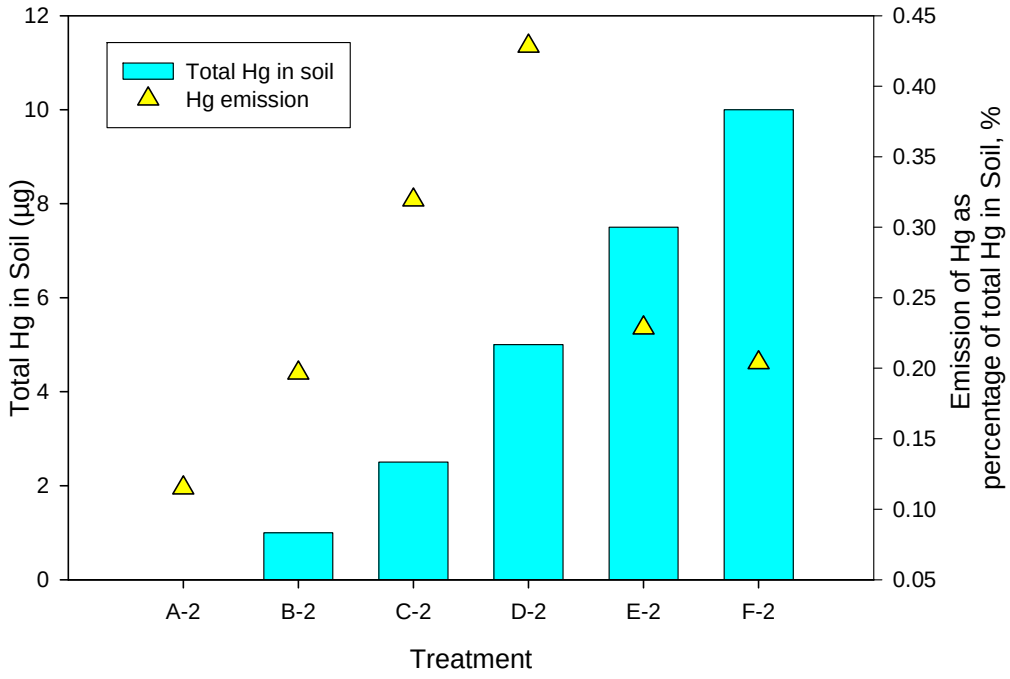


Figure 3.8 Ratio of Hg emission to the total Hg in soil amended with various dosages of SNO FGD material and 1% chicken litter

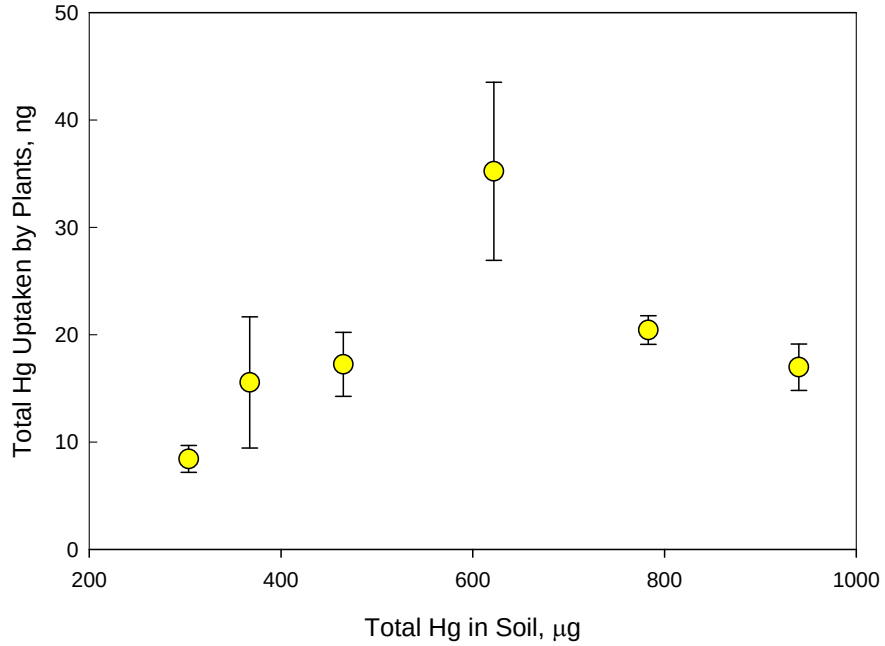


Figure 3.9 Correlation between Hg uptake by plants and total mass of Hg in soil treated with various dosages of SNO FGD material and 1% chicken litter

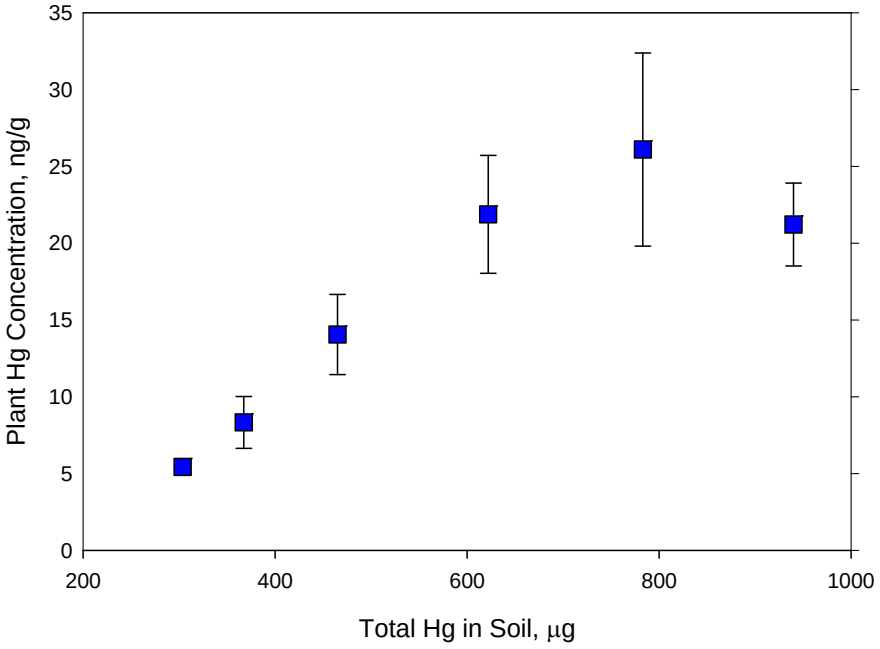


Figure 3.10 Concentration of Hg in the plant from treatments containing SNO FGD material and 1% chicken litter

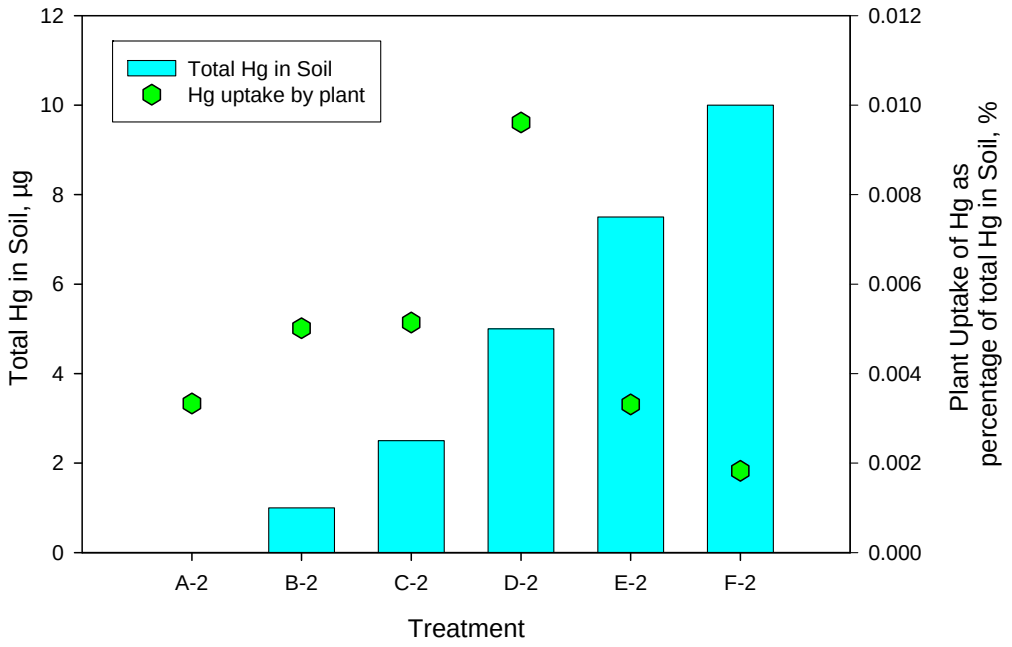


Figure 3.11 Ratio of Hg uptake by plant to the total Hg in soil amended with various dosages of SNO FGD material and 1% chicken litter

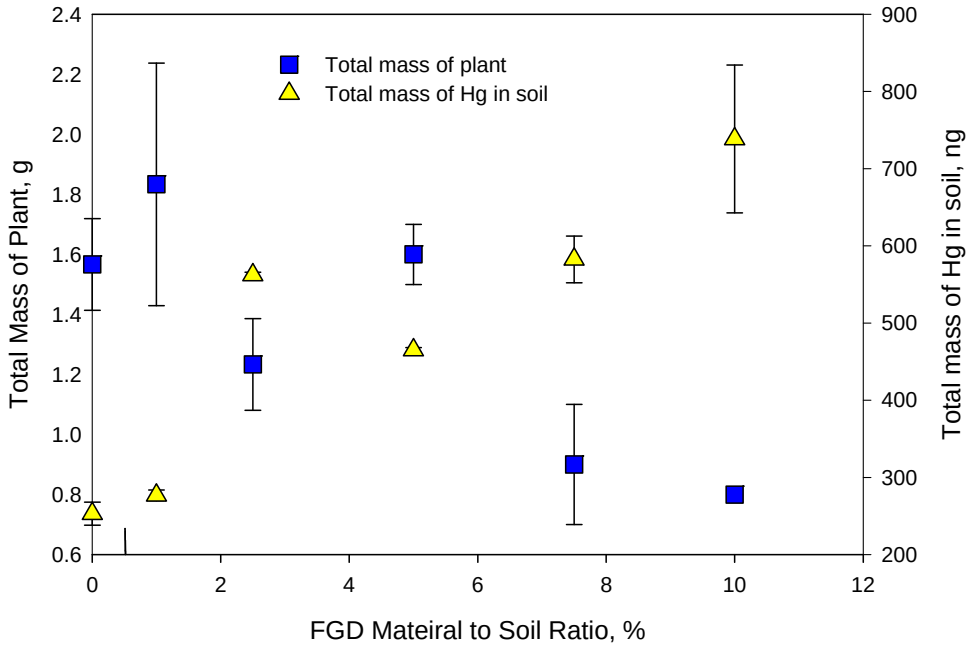


Figure 3.12 Mass of plants with various dosages of SNO FGD material and 1% chicken litter

Figure 3.10 shows the correlation between Hg concentration in the plant and the total Hg in the soil. As shown, the concentration increased as the total mass of Hg increased in the soil. It reached a plateau when the total mass of Hg in the soil was higher than 800μg.

By comparing the total mass of plant uptake of Hg and the total mass of Hg in the soil (Figure 3.4), it was found that the uptake of Hg by plants was not proportional to the total mass of Hg in the soil. The uptake of Hg by plants during the 4 weeks of greenhouse studies did not exceed 0.01% of the Hg in the soil.

Release of Mercury into Infiltration

As shown in Table 3.2, no detectable Hg concentration level was found in the infiltration collected at the bottom of each greenhouse chamber.

Plant Yield

The yield of plants in each chamber as a function of the total mass of Hg in plants can be seen in Figure 3.12. It was found that the yield of plants was higher at the 1% SNO treatment compared to the blank. However, as the ratio of the SNO treatment increased, the yield, in general, showed a decreasing trend.

3.1.3. Effect of Various FGD Materials

The effect of three different FGD materials with the addition of 1% chicken litter was studied during the Third batch of the greenhouse study. Results obtained from the Batch Three experiment can be seen in Table 3.3.

Table 3.3 Total Mass of Hg in Emissions, Plants, Soil, and Infiltration with 1% Chicken Litter and Three Different FGD Materials

Treatment	FGD Material to Soil Ratio[1]	Total Hg[2]	Emission / Dry[3]	Plants			Soil	Infiltration
	% (wt/wt)	μg	μg	Yield, g[9]	ng/g[4]	ng[5]	μg/g[6]	ng[7]
A-3 (blank)	0	215	1.5±0.5	1.23±0.15	11.2±1.1	14±2	14.4±0.3	<4[8]
B-3	SNO 1.0	233	2.6±0.5	0.87±0.06	19±4	16±4	18.2±1.9	<10
C-3	AFO-CPS 1.0	8860	2.4±0.5	1.07±0.12	14.1±1.3	15.1±1.3	260±140	<5
D-3	AFO-CPS 10	86700	8.3±0.6	1.2±0.5	44±13	51±13	2500±400	<8
E-3	AFO-Gypsum 1.0	313	2.25±0.05	1.2±0.4	12.3±0.7	15.0±0.7	23±9	<14
F-3	AFO-Gypsum 10	1190	3.3±0.2	1.50±0.10	22±4	33±4	100±20	<15

[1] as received basis
[2] the total Hg was calculated by the sum of total Hg in soil and the amount of Hg added into the soil as a result of FGD material addition
[3] the total mass of emission was determined by the amount of Hg captured by the carbon trap at the airflow outlet of the chamber
[4] ng of Hg in 1g of plant
[5] the total mass of Hg uptake by the plants was determined by the concentration of Hg in the plants and the total mass of the plants collected from each chamber
[6] dry basis.
[7] the total mass of Hg in infiltration was determined by the concentration of Hg in filtrate and the volume of infiltrate collected at the end of experiment
[8] the Hg concentration level in the filtrate was below the method detection limit (MDL) of 0.1ng/mL.
[9] dry basis

Emission of Mercury

Table 3.3 demonstrates the total mass of Hg release from the soil for each of the six FGD material treatments with an addition of 1% chicken litter. The expected total Hg in soil based on mass calculation was also included in the table for each treatment. As shown, for a given type of AFO FGD material, the emission of total mercury from FGD material/chicken litter-treated soil increased as the total Hg in the soil increased. The correlation can be clearly seen in Figure 3.13. As shown, when compared to the AFO-Gypsum treatment, the emission of Hg increased from about 2.2μg to 3.3μg as the amount of Hg in the soil increased from 313 to 1200μg. The same trend can also be found in the AFO-CPS treatment.

The ratio of Hg emissions to the total Hg in the soil of each treatment can be seen in Figure 3.14. As shown, over 1% of the total Hg in the soil was emitted into the headspace of the greenhouse chamber with 1% of SNO FGD material treatment. Although there were much higher concentrations in the soil for the AFO-CPS batches, less than 0.03% of the total Hg was released. In the case of AFO-Gypsum batches, the release of Hg into the gaseous phase was less than 0.8%.

Uptake of Mercury by Plants

The correlation between the uptake of Hg by the plants and total mass of Hg in the soil is shown in Figure 3.15. When comparing the same FGD material with different dosages, it was found that the uptake of Hg increased as the total amount of Hg in the soil increased. For example, a total of 15ng of Hg was uptaken by the plants in the 1% AFO-Gypsum treatment chamber, which is a little higher than what was observed in the blank chamber, but less than the 10% AFO-Gypsum treatment. It is also true for the AFO-CPS treatment.

When comparing the same treatment dosage with different FGD materials, it was found that both 1% AFO-Gypsum and 1% AFO-CPS showed lower Hg uptake than the 1% SNO treatment. The concentration of Hg in the plant can be seen in Figure 3.16.

The ratio of Hg mass uptake by plant and soil can be seen in Figure 3.17. Less than 0.007% of Hg was taken up by plants with 1% SNO treatment. For the AFO-Gypsum and AFO-CPS treatments, the highest uptake rate was about 0.005% and 0.0002%, respectively.

Release of Mercury into Infiltration

As with what was observed from the other two batches, the Hg concentration in the infiltration collected from the bottom of each chamber was less than the analytical detection limit of 0.1ppb. Therefore, no detectable Hg was found in the infiltration.

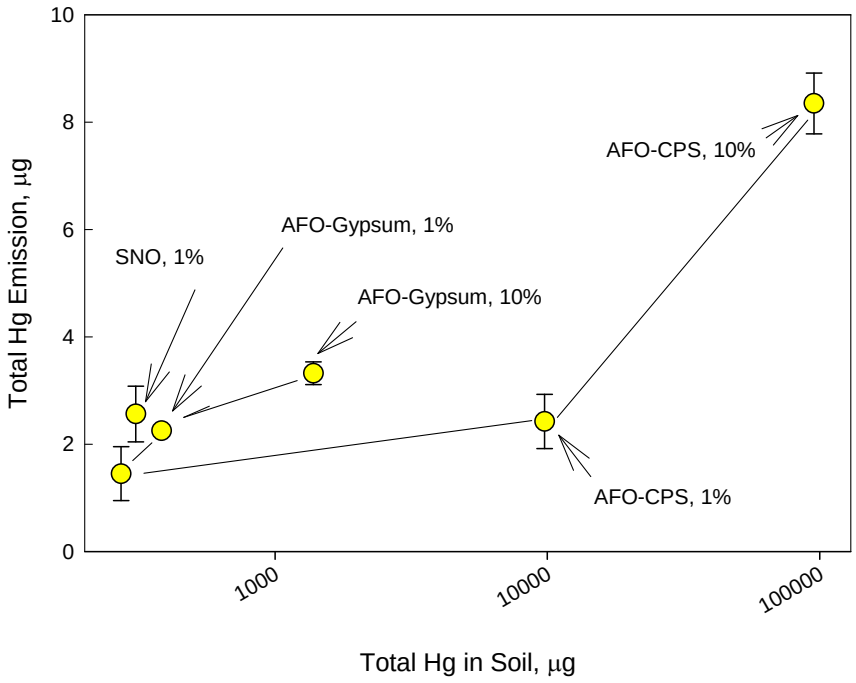


Figure 3.13 Correlation between Hg emissions and total mass of Hg in soil treated with various dosages of three FGD materials and 1% chicken litter

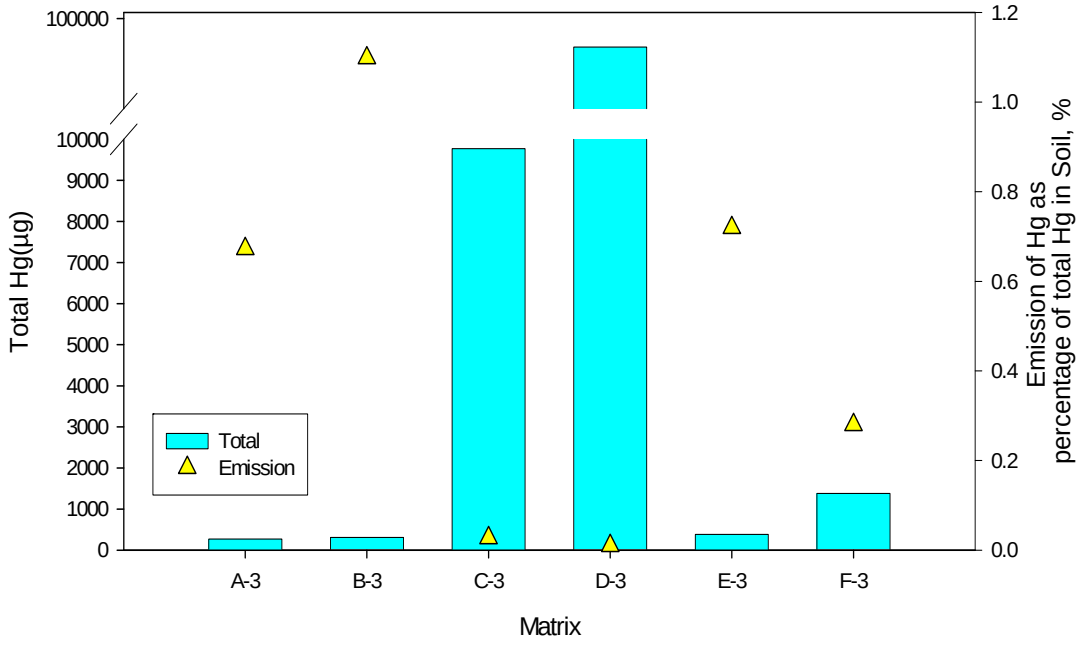


Figure 3.14 Ratio of Hg emissions to the total Hg in soil amended with various dosages of three types of FGD materials and 1% chicken litter

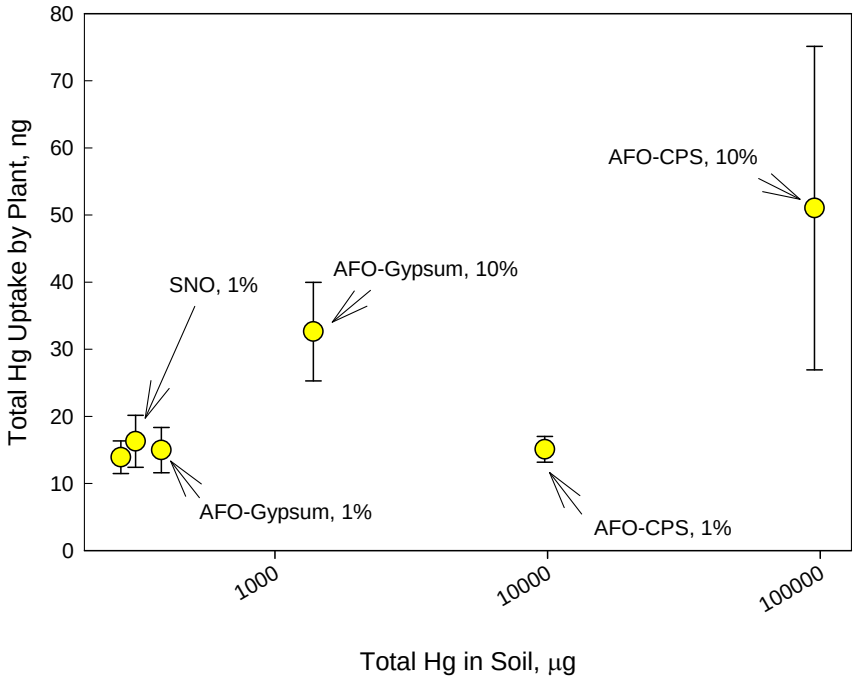


Figure 3.15 Correlation between Hg uptake by plants and total mass of Hg in soil treated with various dosages of three FGD materials and 1% chicken litter

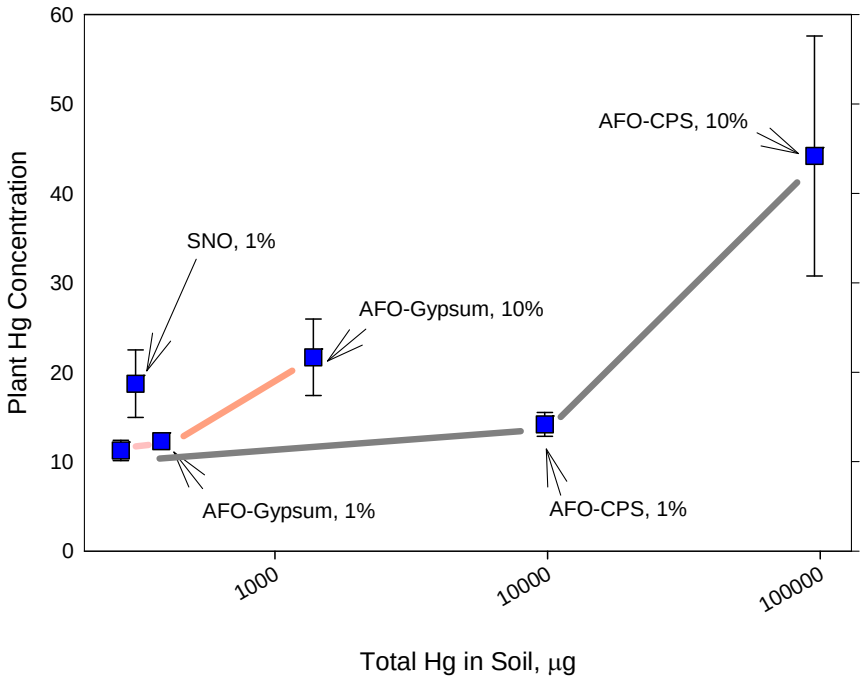


Figure 3.16 Correlation between plant Hg concentration and total mass of Hg in soil treated with various dosages of three FGD materials and 1% chicken litter

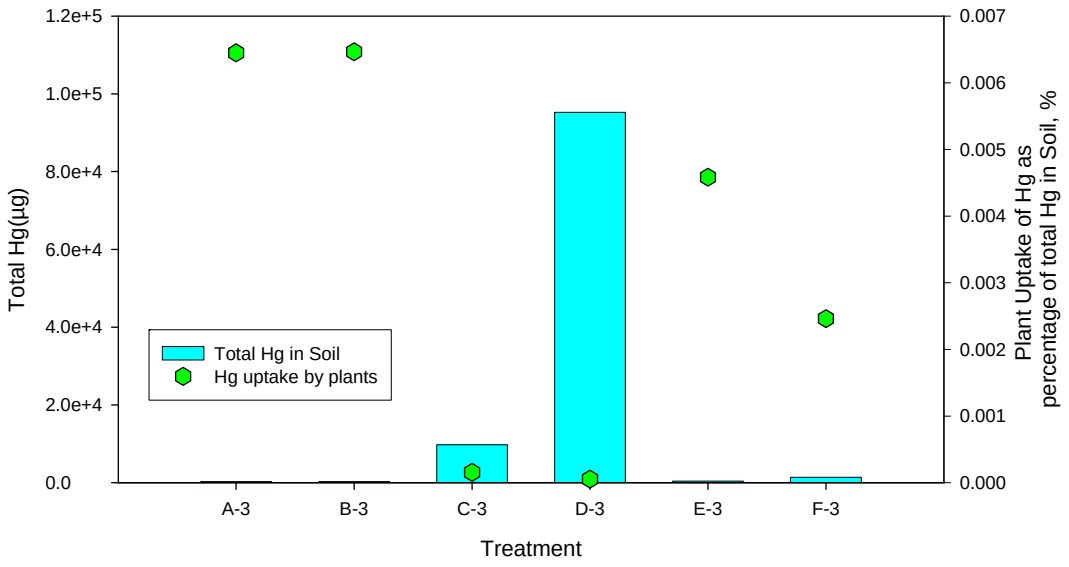


Figure 3.17 Correlation between plant Hg concentration and total mass of Hg in soil treated with various dosages of three FGD materials and 1% chicken litter

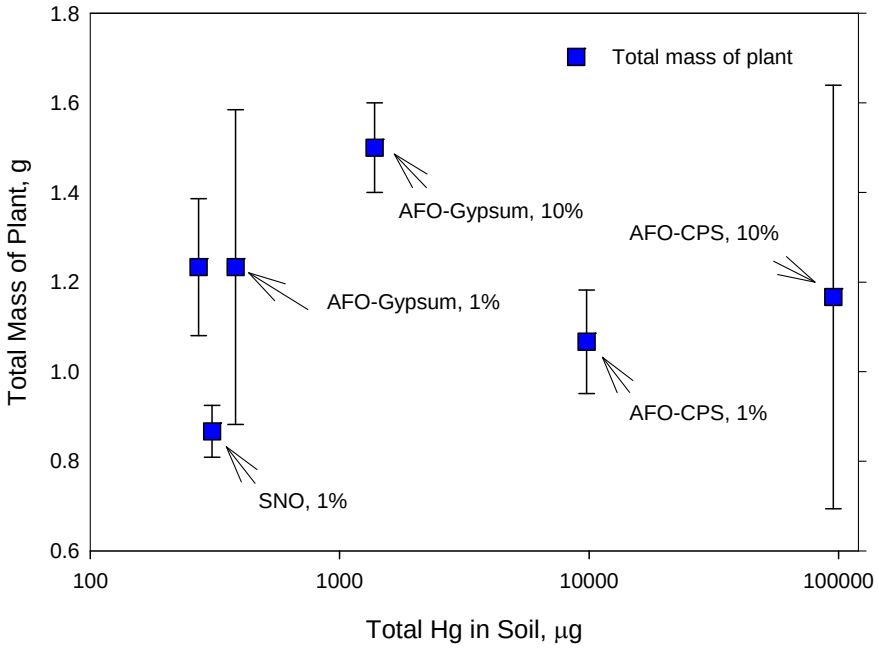


Figure 3.18 Correlation between plant Hg concentration and total mass of Hg in soil treated with various dosages of three FGD materials and 1% chicken litter

3.2. Field Study

The field study was carried out to investigate the effect of various FGD materials with a same FGD-material-to-soil ratio of 1%. Results obtained from the field study can be seen in Table 3.4.

As shown in Table 3.4, the total mass of mercury emission from the SIPC 1.0% treatment was higher than the other plots. The total mass of mercury emissions shown in the table is the mass of Hg captured by the sorbent trap during the testing period. The Hg emissions sampling chamber covered 225cm^2 of the 10000cm^2 testing area. The grass samples collected from the treatment of AFO-CPS 1.0% plot had the highest mercury concentration level of about 1900 ng/g. It was also found that The AFO CDS 1.0% had the lowest yield of grass among the four treatments.

No detectable concentration level of Hg was found in the infiltration.

Table 3.4 Total Mass of Hg in Emissions, Plants, Soil, and Infiltration with 1% Chicken Litter and Three Different FGD Materials

Treatment	FGD Material to Soil Ratio[1]	Soil Hg[2]		Emission	Plants			Infiltration
		0-15[3]	15-30[4]	Dry[5]				
	% (wt/wt)	ng/g	ng/g	µg	Yield, g/cm^2	ng/g[4]	ng[5]	ng/mL[7]
A-Field (blank)	0	35±5	22±4	0.44±0.02	240±80	20.0±1.4	4700±1500	<0.1
B-Field	SNO 1.0	39±8	20±8	2.5±1.5	190±100	55±19	13100±1400	NA
C-Field	AFO-CPS 1.0	4790±30	40±10	1.4±0.8	150±70	1900±900	400±300[8]	<0.1
D-Field	AFO-Gypsum 1.0	71±18	18±2	0.76±0.15	240±33	61±4	15000±4000	NA

[1] the ratio is in as received basis
[2] the results are from analysis after experiment
[3] section between surface and 15cm deep into ground
[4] section between 15-30cm deep into ground
[5] the total mass of emission was determined by the amount of Hg captured by the carbon trap at the airflow outlet of the chamber, which represented 225cm^2 of the total 10000 cm^2 testing area.
[4] ng of Hg in 1g of plant
[5] the total mass of Hg uptake by the plants was determined by the concentration of Hg in the plants and the total mass of the plants collected from each chamber
[6] the total mass of Hg in the soil was determined by the concentration of Hg in the soil and the mass of the soil in each chamber after experiment.
[7] the total mass of Hg in infiltration was determined by the concentration of Hg in filtrate and the volume of infiltrate collected at the end of experiment
[8] the unit is in µg

3.2.1. Emission of Mercury

Figure 3.19 demonstrates the correlation between the total mass of mercury emissions and the mercury concentration in the soil. As shown, all the FGD material-treated soil emitted more Hg than the blank soil plot. The highest emission rate of Hg was found to be from the SNO treatment. Although the soil of AFO-CDS plot contained the highest Hg concentration, the sorbent trap did not collect the highest amount of Hg emissions based on the average of the triplicates.

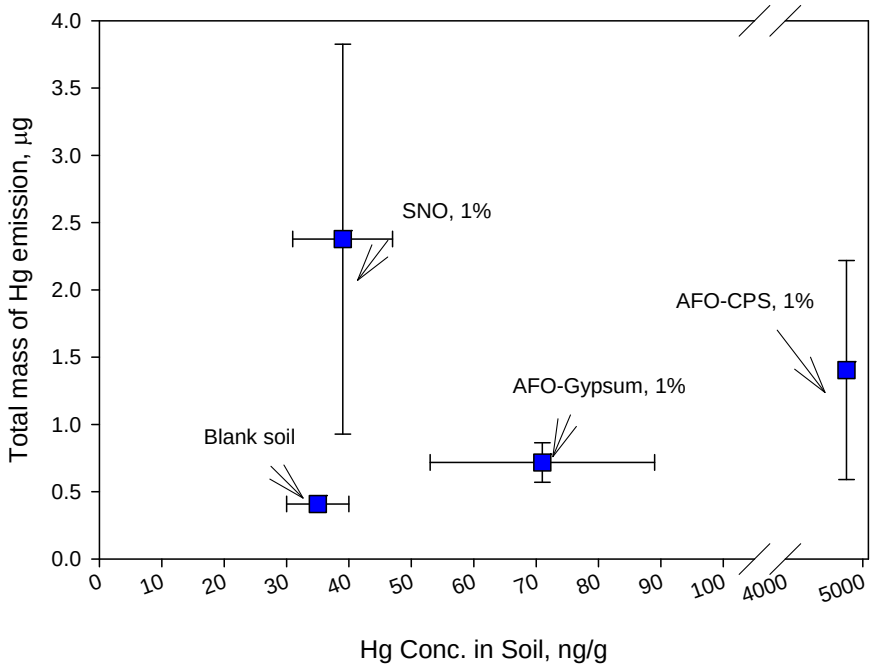


Figure 3.19 Mass of Hg emissions collected during the testing period in the field study

3.2.2. Plant Uptake

The concentration of Hg in the plant was found to be highest at the AFO-CPS plots with a concentration of 1900±900ng/g. Although the soil Hg concentration in the AFO-Gypsum plots was higher than what was found in the SNO plots, there was no noticeable difference in the plant Hg concentration found between the AFO-Gypsum and SNO plots. The plants collected from the plots with no FGD material treatment contained the lowest Hg concentration.

3.2.3. Plant Yield

The concentration of Hg in the plant was highest at the AFO-CDS plots with a concentration of 1900±900ng/g. Although the soil Hg concentration in the AFO-Gypsum plots was higher than what was found in the SNO plots, no noticeable difference in the plant Hg concentration can be found between the AFO-Gypsum and SNO plots. The plants collected from the plots with no FGD material treatment contained the lowest Hg concentration.

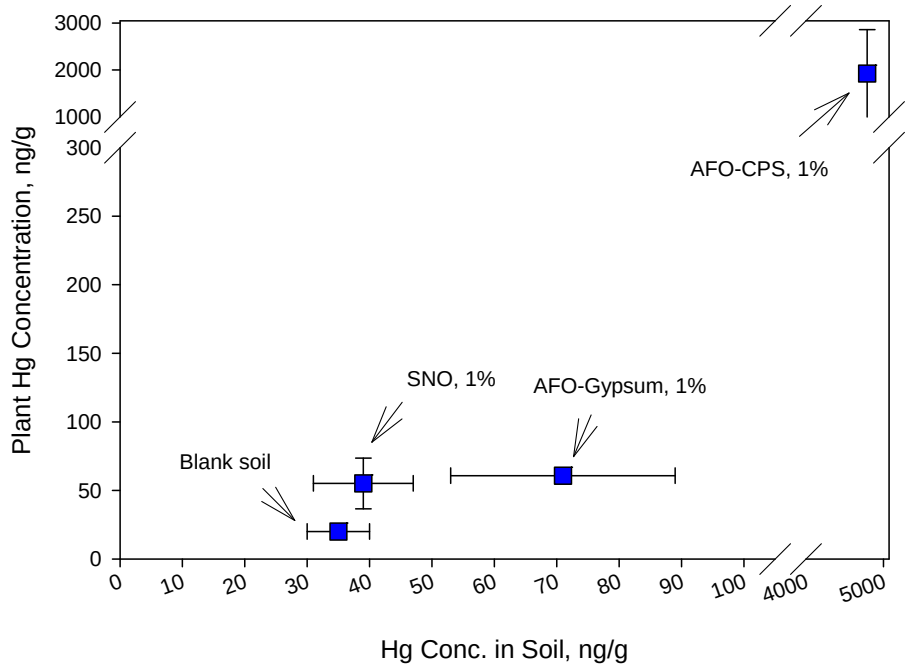


Figure 3.20 Correlation between total mass of Hg collected and Hg concentration in soil

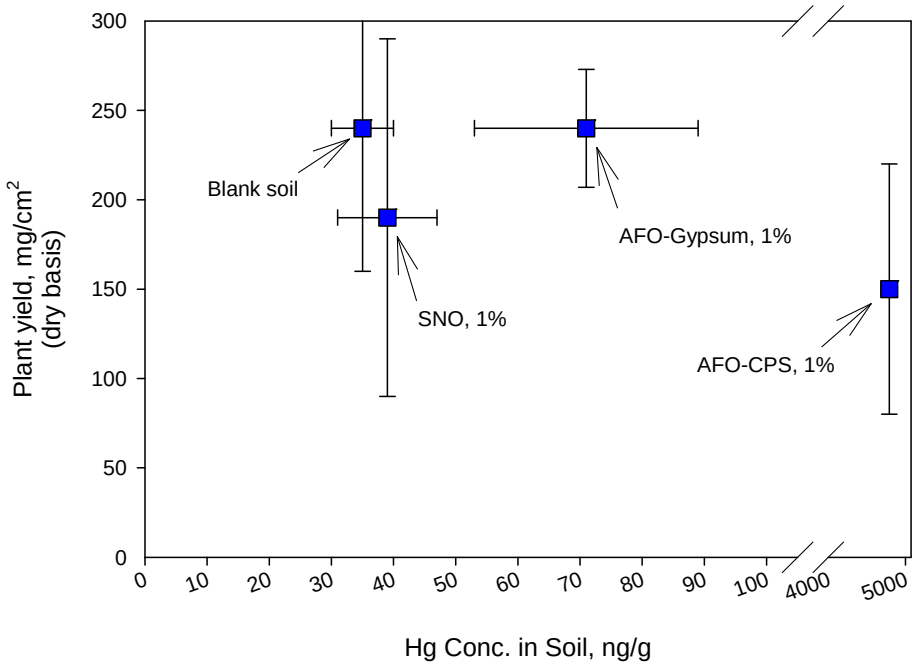


Figure 3.21 Correlation between total mass of Hg collected and Hg concentration in soil

4. Life Cycle Assessment

In this study, life cycle assessment was applied to evaluating the environmental impact of using different FGD materials as soil amendments.

The S plant impounded all the naturally-oxidized FGD material in an impoundment site across the plant. For the A plant, all (100%) of the produced gypsum was used for wallboard production. The sludge produced from the chloride purge stream was transported to a nearby impoundment site.

4.1. Life Cycle Inventory

The production of FGD material for every 1,000kg of coal combusted in the two coal combustion facilities is listed in Table 4.1. It was calculated based on the data provided by the tested facilities. The concentrations of Hg in the coals used by the two tested facility are summarized in Table 4.2.

Table 4.1 The Production of FGD Material

	SNO	AFO-Gypsum	AFO-CPS
FGD material production	160	120	20

kg/1000kg of coal combusted

Table 4.2 Concentration of Hg in the coal and FGD material

	Plant S	Plant A	
Hg concentration in coal, μg/g	0.082±0.011	0.14±0.06	
Coal flow rate, Ton/hour	120	580	
Load, MWe	176	795	
FGD Material	SNO	AFO-Gypsum	AFO-CPS
Hg Concentration, μg/g	0.24	0.74	63.3
% of Hg in coal found in the FGD material	0.51	0.63	0.01

kg/1000kg of coal combusted

4.2. Release of Hg

4.2.1. Hg Emissions

The comparative life-cycle Hg emissions of soil amended with three different FGD materials is discussed using data obtained from the field study. Results can be seen in Table 4.3. Note that the total mercury emission was obtained from multiplying the total amount of Hg captured by the carbon trap during the same period of time by the ratio between the area of the testing plot and Hg emission sampling chamber. The amount of Hg emissions due to the addition of FGD material was calculated by subtracting the emission of Hg from blank soil from the emission of FGD material-treated batches. Also, it was assumed that 100% of produced FGD material was used for soil amendment.

Based on the calculation, nearly 6% of total Hg that was added into the soil as a result of SNO treatment was released into the gaseous phase. The ratio was found to be much higher than what was observed in the greenhouse studies. It is likely due to the

increased opportunity for the carrier air to come in contact with the soil-FGD material mixture in the field study. In the greenhouse study, unlike the field study, less carrier air came into contact with the deeper layer of the soil-FGD material matrix. The sampling chamber used in the field study was inserted approximately 2cm into the soil to make sure no ambient air slipped into the chamber from the contact point between the edge of the chamber and soil. As a result, it was likely that some air was pulled through the soil matrix and had carried more Hg from the matrix. It was calculated that about 2.3×10^{-6} kg of Hg was released into the atmosphere when 1000kg of coal was burned. It was under the condition that 100% of the SNO FGD material generated from the S plant was used as a farm amendment.

Under the same assumption, the other two FGD materials released 1.33×10^{-7} kg and 2.79×10^{-7} kg into the atmosphere during the testing period.

Table 4.3 Life-cycle Hg Emission of Soil Amended with three different FGD materials

Treatment	FGD Material to Soil Ratio[1]	Soil Hg[2] 0-15[3]	Total Net Hg Emission due to FGD Material Addition	Hg Released	**kg of Hg release per 1000kg of Coal Burned**
	% (wt/wt)	ng/g	μg	% of total Hg	
B-Field	SNO 1.0	39±8	97.4	6.28	2.26E-06
C-Field	AFO-CPS 1.0	4790±30	48.5	0.011	1.33E-07
D-Field	AFO-Gypsum 1.0	71±18	18.2	0.314	2.79E-07

[1] the ratio is in as received basis
[2] the results are from analysis after experiment
[3] section between surface and 15cm deep into ground

4.2.2. Hg Uptake by Fescue Grass

The comparative life-cycle uptake of Hg by plants with three different FGD materials is discussed using data obtained from the field studies. Results can be seen in Table 4.4. The amount of Hg uptake due to the addition of FGD material was calculated by subtracting the emission of Hg in blank soil from the emission of FGD material-treated batches. Also, it is assumed that 100% of produced FGD material was used for the soil amendment.

Table 4.4 Life-cycle Hg Uptake by Fescue Grass with Three Different FGD Materials

Treatment	FGD Material to Soil Ratio[1]	Soil Hg[2] 0-15[3]	Total Net Hg uptake by Plants due to FGD Material Addition	Hg uptake	**kg of Hg/1000kg of Coal Burned**
	% (wt/wt)	**ng/g**	**ng**	**% of total Hg**	
B-Field	SNO 1.0	39±8	8.40E+03	7.54E-01	1.95E-07
C-Field	AFO-CPS 1.0	4790±30	3.95E+05	8.58E-02	1.08E-06
D-Field	AFO-Gypsum 1.0	71±18	1.03E+04	1.98E-03	1.58E-07

[1] the ratio is in as received basis
[2] the results are from analysis after experiment
[3] section between surface and 15cm deep into ground

4.2.3. Total Release of Hg

The life-cycle release of Hg using FGD material as a soil amendment can be seen in Table 4.5. As shown in the table, the SNO FGD material released the most Hg during the testing period. The AFO-Gypsum treatment had the least release of Hg.

Table 4.5 Release of Hg from Soil Amended with Three Different FGD Material

Treatment	FGD Material to Soil Ratio[1]	Soil Hg[2] 0-15[3]	Emission	Hg uptake	**Total**
	% (wt/wt)	**ng/g**	**kg of Hg/1000kg of Coal Burned**		
B-Field	SNO 1.0	39±8	2.26E-06	1.95E-07	2.46E-06
C-Field	AFO-CPS 1.0	4790±30	1.33E-07	1.08E-06	1.22E-06
D-Field	AFO-Gypsum 1.0	71±18	2.79E-07	1.58E-07	4.37E-07

4.3. Limitation

The goal of this LCA was not to calculate absolute impact quantities but to compare trends in FGD material amendments. Release of heavy metals from FGD material amended soil is expected to create impacts in human toxicity and ecotoxicity categories. However, due to the limited project period, it is unknown how long the release of Hg will last or if the magnitude will change over time.

5. Discussion and Conclusions

5.1. Factors Controlling the Emission of Hg from Soil Amended with FGD Materials

Based on the greenhouse experiments, it was found that the moisture content of the soil, the Hg concentration in the soil, and the types of FGD Materials affected the emission of Hg in this study.

The effect of moisture content in the soil on the Hg emission can be seen in Figure 4.1. As shown, the emissions of Hg from soil increased as the moisture content in the soil increased. This is true for both soils with and without SNO FGD material treatment. For example, in the case of the soil with 1% SNO FGD material treatment, it was found that when the moisture content in the soil increased from 17 to 28.5%, the total mass of Hg emissions increased from 1.8 to 8ng.

Another key factor that affected the release of Hg into the head space of the greenhouse chamber was the concentration of Hg in the soil. As shown in Figure 4.2, it was found that, in general, the emissions of Hg increased as the concentration in the soil increased. The increasing trends can be found for all of the three FGD materials tested in this study.

However, the Hg emission behaviors from soils treated with different FGD materials were different. In Figures 3.13 and 3.19, the total mass of Hg emissions did not increase when the Hg concentration in the soil increased as a result of the addition of different FGD materials. In general, with the same amount of FGD material, the addition of SNO FGD material produced the soil sample with the lowest Hg concentration among the three FGD material treatments. However, the SNO treatment batch showed the highest Hg emissions. The results suggest that the types of FGD material also have significant effect on Hg emissions. The variation of Hg species in the FGD material might have caused the observation. The forced oxidation and chemical coagulation processes involved in the production of AFO-Gypsum and AFO-CPS might have transformed Hg into other species that were less soluble or volatile. Further study is needed to elucidate the controlling mechanisms.

5.2. Factors Controlling the Uptake of Hg by Plants

The concentration of Hg in the soil and types of FGD materials are likely the most important factors that controlled the uptake of Hg by plants during the testing. As shown in Figure 4.3, for a given FGD material, the Hg concentration level in the plants increased as the concentration of Hg in the soil increased. As with emissions, uptake of Hg was also different among the three FGD materials tested. With the same amount of FGD material, Batch Three of the greenhouse study showed that the highest Hg concentration in the plant was served in the SNO FGD material treatment (Figure 3.16) although the addition of AFO-Gypsum and AFO-CPS produced higher Hg concentration

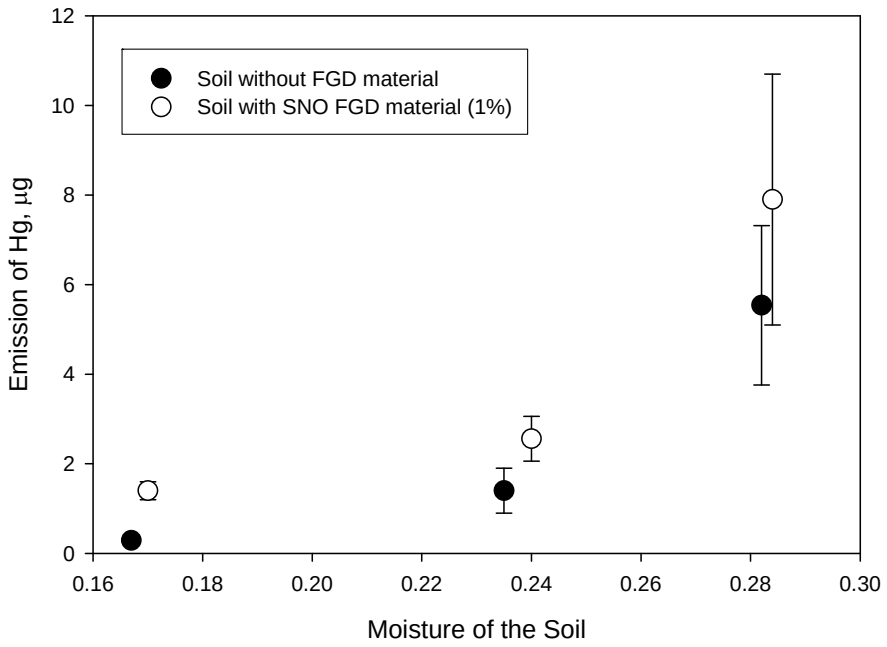


Figure 5.1 Correlation between total Hg emissions and soil moisture

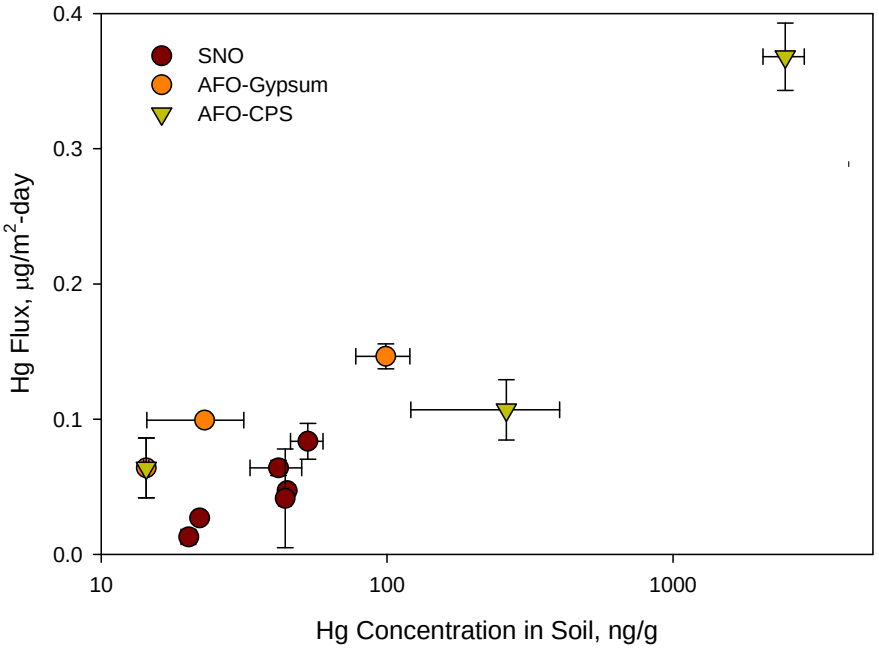


Figure 5.2 Correlation between Hg emissions flux and Hg concentration in soil

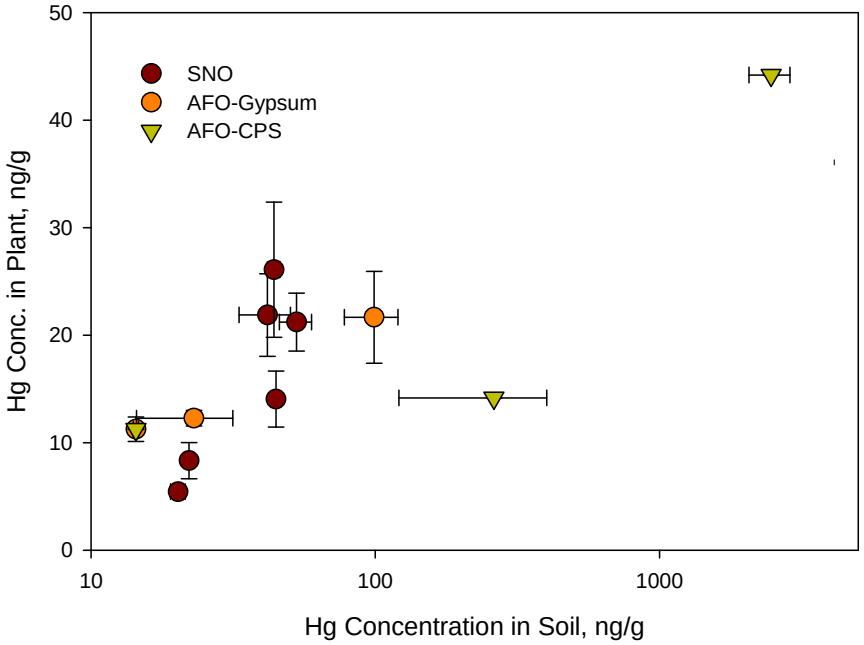


Figure 5.3 Correlation between Hg concentrations of the plants and soil Hg concentration

in the soil, the uptake of Hg by plants was not as quick as what was observed in the SNO treatment.

Although the experimental conditions were different between the greenhouse and field studies, results from Batch Three of the greenhouse and field studies suggested that the types of plants also affect the uptake of Hg. For example, with the same FGD material addition ratio, the concentration of Hg in Fescues Grass is much higher than what was observed in the corn, especially with 1% of AFO-CDS treatment.

By comparing the soil moisture content, it was found that, without the addition ofFGD material, the Hg concentration in the plant increased as the moisture of the soil increased. However, the increasing trend was not obvious in the 1% SNO treatment. As a result, the effect of moisture on the uptake of Hg was not conclusive.

5.3. Release of Hg into Infiltration

No detectable Hg concentration level was found in the infiltration samples collected from the three batches of greenhouse studies. All the Hg concentration levels were less than 0.1 ppb of detection limits. By taking the amount of infiltration collected during each experiment, less than 50ng of Hg was released into the infiltration.

The lysimeter system applied in the field study did not collect infiltration effectively. Only infiltration samples from A (blank) and one of the C (1% AFO-CPS)

batches were available. As with the laboratory study, no detectable Hg level was observed.

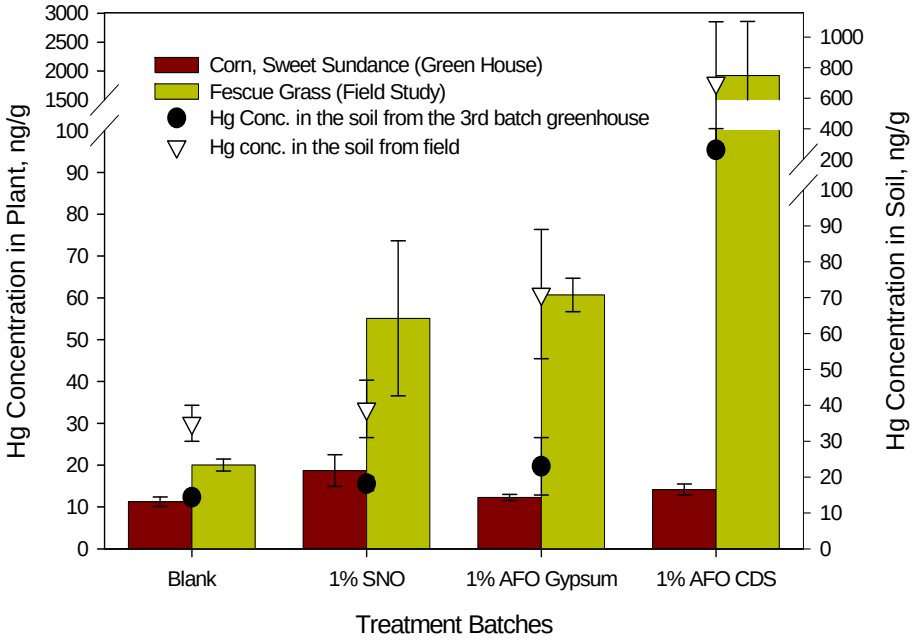


Figure 5.4 Correlation between Hg concentration of the plants and soil Hg concentration

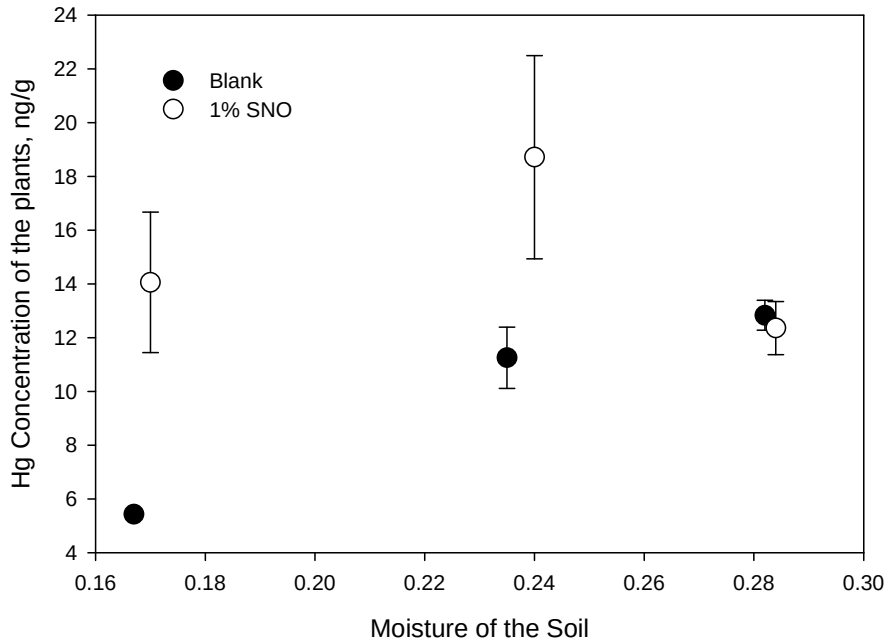


Figure 5.5 Correlation between Hg concentration of the plants and soil moisture

5.4. Effect of FGD Material Additions on the Yield of Plants

According to the results from the Batch Two greenhouse study, the addition of SNO FGD material showed a negative effect on the growth of corn. This conclusion was validated by the results from both Batch Three and field studies.

In the case of AFO-Gypsum, the total mass of corn did not show observable increases with 1% of AFO-Gypsum treatment in both Batch Three and field studies. But with 10% treatment, the total mass of the plants was significantly higher than the blank soil. Although not many data points demonstrated the trend, the addition of AFO-gypsum likely had a positive effect on the growth of plants.

As with the SNO FGD material, the AFO-CPS material showed a negative effect on the growth of both corn and grass. It is likely due to a higher uptake of Hg and other trace element from the AFO-CPS treated soil.

5.5. Environmental Impact Associated with Using FGD-Material as Soil Amendments

Results obtained from life cycle analysis suggested that the AFO-Gypsum would release the lowest amount of Hg into the environment when all three FGD materials were compared under the same operation assumption. However, all the experiments were carried out within a limited timeframe. Long-term experiments are needed to further investigate the effect of aging on the release of Hg into the environment.